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ENVIRONMENTAL PLANNING FOR THE METROPOLITAN AREA CEDAR-GREEN RI--ETC(U)

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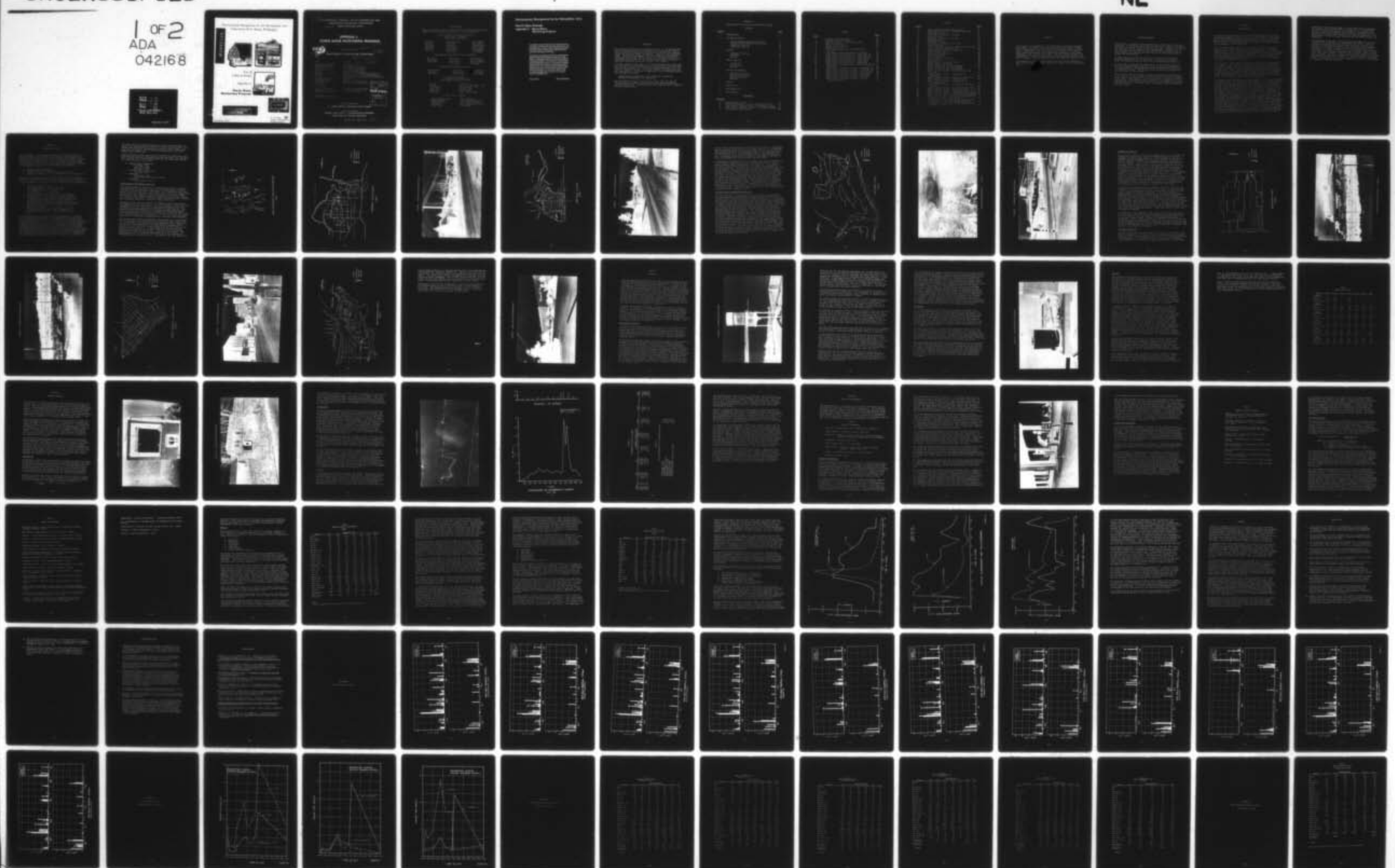

Environmental Management for the Metropolitan Area
Cedar-Green River Basins, Washington

Part II
Urban Drainage

Appendix C

Storm Water Monitoring Program

U. S. Army
Corps of Engineers
Seattle District

December 1974

(6)

ENVIRONMENTAL PLANNING FOR THE METROPOLITAN AREA
CEDAR-GREEN RIVER BASINS, WASHINGTON.
Part II. URBAN DRAINAGE STUDY.

APPENDIX C.
STORM WATER MONITORING PROGRAM,

RIBCO LAND AIR WATER WASTE

(11) Dec 74

Technical Direction by

(12) 107p.

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ACKNOWLEDGMENTS

The Corps of Engineers expresses appreciation to the following individuals and groups for their assistance in conducting the Urban Drainage Study:

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Environmental Management for the Metropolitan Area

Part II Urban Drainage

Appendix C Storm Water Monitoring Program

This appendix material related to urban drainage prevention and control in the Cedar and Green River basins is part of an integrated study of water and waste management sponsored by the Municipality of Metropolitan Seattle through the River Basin Coordinating Committee.

The appendix was prepared by Glen Farris, Superintendent, Robert G. Swartz, Bacteriologist, and Norman R. Wells, Chemist, of the Water Quality Division of the Municipality of Metropolitan Seattle. The full report on urban drainage was the responsibility of the U.S. Army Corps of Engineers Seattle District, with funding from a Congressional appropriation to the Corps. Technical studies for the full report were performed for the Corps by the consulting firms of Kramer, Chin & Mayo, Inc., and Yoder, Trotter, Orlob & Associates, Walnut Creek, California, a joint venture Known as KCM-WRE/YTO.

October, 1974 Seattle, Washington

ABSTRACT

The quantity and quality of stormwater runoff in the Metropolitan Seattle, Washington area was measured over a seven-month period. Survey sites were selected on the basis of land use and included single and multiple family residential, commercial and industrial areas. Quantity measurements involved continuous recording of stormwater runoff and rainfall volume and intensity while quality measurements were made for 29 parameters with samples taken at specified intervals during the course of six storms.

Rainfall intensity was light for the monitoring period, resulting in a relatively low percentage of stormwater runoff factors, which varied from 5 percent for low density residential areas to 64 percent for commercial areas. Pollutant washoff loading varied with land use pattern. The order of magnitude in an increasing pattern was recorded as follows:

> single family residential; new commercial; industrial; multiple residential; old commercial.

The pollutants of major concern were solids, BOD, COD and oil. Nutrient and heavy metal loading values with some exceptions, were relatively low. Coliform values were high but not of apparent sanitary significance.

APPENDIX C

WATER QUALITY AND QUANTITY MONITORING PROGRAM

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TABLES

FIGURES

PREFACE

This report is an appendix to the Urban Runoff and Basin Drainage Study which, in turn, is part of an overall environmental management planning program for the Cedar and Green River Basin in King County, Washington. The overall program includes four studies: Water Quality Management, Water Resources Management, Solid Waste Management, and Land Use Allocation. All were conducted under the supervision of the River Basin Coordinating Committee (RIBCO) with policy guidance from the Municipality of Metropolitan Seattle Council.

This appendix is also produced separately as a Metro publication due to the current widespread interest in urban runoff water quality data.

ACKNOWLEDGEMENTS

Metro wishes to express their appreciation to the Corps of Engineers personnel, in particular Walter Farrar and Merlin Vilhauer, for their assistance in design of the program and for their guidance in carrying out the study and in completion of this document. Appreciation is also extended to Roger Fry and other KCM-WRE/YTO personnel, and to Donald Benson and John Buffo, Metro Staff, for their assistance in design and consultation.

We again wish to express our thanks to the City of Seattle Engineering Department, and in particular to Harvey Duff, George Hsieh and Russell Tobie for their help in supplying rainfall data.

We also wish to express our appreciation to the National Weather Service including Samuel Sigurdson for their help in maintaining a warning system of impending rainstorms which greatly facilitated out sampling program. The NWS-FAA radar facility was likewise an important part of this system.

Metro's Water Quality Division personnel contributed immeasureably to the success of the program. Their extra work effort and standby duty often at the expense of their own personal enjoyment is greatly appreciated. CH2M personnel are likewise to be commended for their contribution to the field sampling effort in the summer period which provided relief for the Metro crews, an important factor during the vacation period.

CHAPTER 1

INTRODUCTION

The Urban Runoff and Basin Drainage Study was designed to provide a drainage management plan for use in the development of the integrated environmental management plan for the Green and Cedar River Basins which was formulated by the River Basin Coordinating Committee (RIBCO). The Water Quality and Quantity Monitoring Program was contributary to the URBD Study.

One of the principle products of the urban drainage study was a computer model capable of planning and analyzing urban drainage systems (EPA, 1971). The model was used to predict the impact of urban drainage on the region's water quantity and quality. Alternate land use concepts and alternate approaches to urban drainage control were considered in the regional analysis. The full capability of the model was demonstrated by analyzing five sub-basins in detail for present and potential problems.

In the study's early stages, local data to calibrate the model was not adequate. Such studies as Metro's combined sewer separation study (Metro Staff, 1971) and freeway runoff study (Farris, et al, 1973) were designed for determination of average daily pollutant loadings only. Flow, quality and rainfall measurements with respect to time were not monitored precisely enough for use in calibrating a hydrologic-quality model. These studies likewise were not designed to describe land use characteristics, which are an important factor in the computer model's predictive capability.

The present monitoring program was developed to provide the necessary calibration data. The study was conducted over a seven-month period from February through September, 1973. Six storms were sampled and analyzed. The monitoring program was terminated after the first intense fall rainstorm following one of the driest spring and summers on record. Although more wet-season data was desired, it was necessary to halt data collection and proceed with calibration of the model in order to meet the date established for completion of the Urban Runoff and Basin Drainage Study. In some cases the rainfall intensity was probably not sufficient to provide complete washoff of pollutants, leading to low washoff loading values. Due to the number of factors affecting pollutant loading (land use, rainfall volume and intensity, number of preceding dry days, maintenance, seasonal effects, etc.), and the short sampling period, this study does not provide a broad statistical base. However, since this is the best data available to date, the present conclusions were drawn in order to establish a tentative basis for calibration of the model. Metro's Water Quality Division is developing a continuing program of monitoring urban stormwater runoff quantity and quality as part of the water quality monitoring network now sponsored by Metro.

Through this continuing program, the data base will be expanded and further data analyses will be accomplished. This data will be used to update and improve the accuracy of the models which will be housed and maintained by King County, and which are expected to be used by local planners and urban hydrologists in the development of urban drainage systems after the RIBCO studies are completed.

The Urban Runoff and Basin Drainage Study was conducted by the U. S. Army Corps of Engineers in cooperation with Metro. With the assistance of RIBCO, the Corps selected the joint venture consulting firm KCM-WRE/YTO (Kramer, Chin and Mayo - Water Resource Engineers, Inc./Yoder, Trotter and Orlol and Associates) to be responsible for model calibration and the principal study analysis. The design of the monitoring program was developed jointly by the three study participants. Sample collection and analysis, primary data management and report preparation were performed by Metro Staff. Funding for the monitoring project was provided by Metro as designated in a Memorandum of Agreement signed with the U. S. Army Corps of Engineers, Seattle District.

CHAPTER 2

CALIBRATION AREAS

The development of the computer model for the urban runoff and basin drainage study required the design and implementation of a stormwater runoff quantity and quality monitoring program to furnish data for calibrating the model. The design of this program involved the selection of specific calibration areas which were representative of the land-use categories being modeled. The land-use categories selected for study included the following:

1. Single family residential;
2. Multiple family residential;
3. Commercial (retail trade, wholesale, services);
4. Industrial (manufacturing, transportation, utilities, etc.)

Because of the close correlation between the accuracy of model simulation and the calibration data, a fairly rigid set of criteria needed to be followed in selection of calibration sites for each land-use category. The primary criteria used in site selection were:

1. Size of calibration area
   (a) single family - 100 to 1000 acres
   (b) multiple family - 80 to 500 acres
   (c) commercial - 25 to 50 acres
   (d) industrial - 50 to 100 acres
2. Uniform and fully developed land use throughout.
3. Representative of the land-use category selected.
4. A separate storm drain system, without connection to the sanitary sewer system, which transports all stormwater runoff within the calibration site.
5. All storm drains within the system must be operating correctly with no flooding, backwater effects or significant ponding.
6. The sites must have a limited number of outflow locations which are positioned to enable easy access and installation of the monitoring equipment.

After extensive plan review and field investigation, it became readily apparent that selection of ideal calibration sites could not be achieved in every case. For example, the combined sewer areas located within a major portion of the City of Seattle seriously limited site selection. One site was finally selected within the combined sewer area because it best represented a typical highly developed commercial area with no suitable site available within the separated sewer areas of the region. Uniform land use was also a very difficult requirement to meet with the exception of the single family residential areas. In addition, well-defined drainage areas and isolated sewer systems were difficult to locate. These difficulties resulted in deviating from the criteria in some cases; but

this did not affect the accuracy of the data collected since the deviations were sufficiently defined to allow for correction. Although some undefined inaccuracies do exist in these cases, they were not considered to be of sufficient magnitude to seriously hamper model calibration.

Seven calibration sites were finally selected for monitoring which represent the land-use categories selected and which, for the major part, fulfill the criteria established for site selection (Figure 1). These areas are as follows:

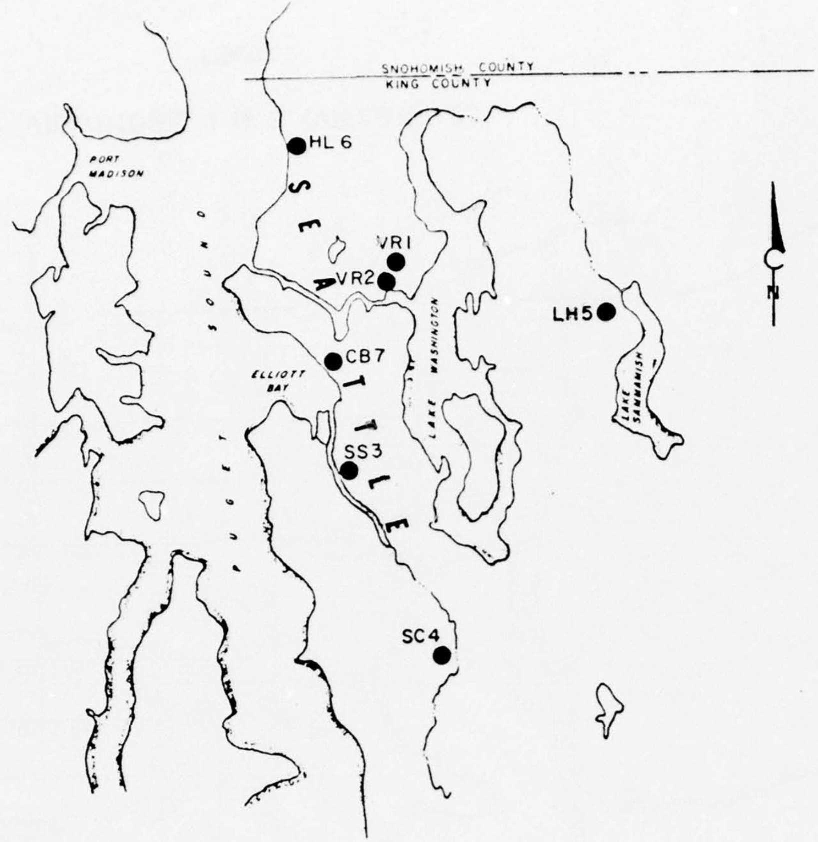
1. Single family residential
   - Viewridge (VR1)
   - Lake Hills (LH5)
   - Highlands (HL6)
2. Multiple family residential
   - Viewridge (VR2)
3. Commercial
   - Southcenter (SC4)
   - Central Business District (CBD7)
4. Industrial
   - South Seattle (SS3)

SINGLE FAMILY RESIDENTIAL LAND USE

The Viewridge area is located in the Northeast section of the City of Seattle and is primarily a high density single family residential area containing mostly older homes. The calibration site (VR1) within this area comprises a total land area of 630 acres (Figure 2). The lot sizes are typically small and contain an average of 5000 square feet, which equals about nine housing units per acre (Figure 3). The site lies within a shallow valley that drains south to Union Bay descending through an elevation change of 100 feet.

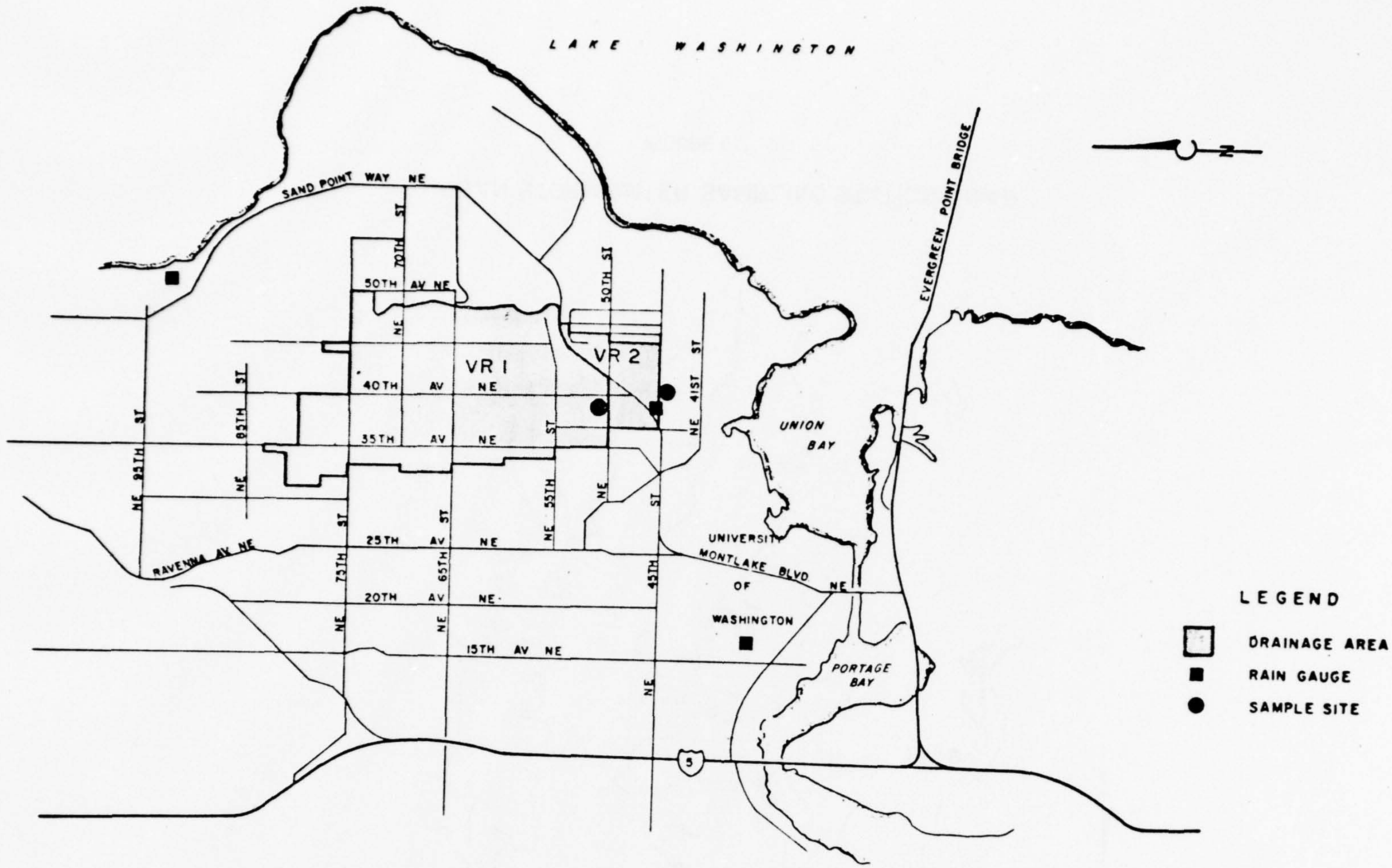
Originally, this area was served by a combined sewer system which was separated in the late 1960's. All catch basins in the area were connected to the new storm drain system, but downspouts from the residences are still tributary to the sanitary sewer system. The estimated area represented by roof drainage is approximately equivalent to 30 percent of the total drainage area within the basin. The sampling station for this site is located in a hole at the corner of N. E. 50th Avenue and 40th Avenue N. E. At this point the storm drain line is 54 inches in diameter with a slope of 0.024 inch/foot.

The second single family residential area selected as a calibration site is located in the Lake Hills area about five miles east of the City of Bellevue and overlooks the Lake Sammamish Valley (Figure 4). The site is a 150-acre section of medium density housing with a typical lot size of 7200 to 10,000 square feet and from four to six houses per acre (Figure 5). A minor amount of multiple housing exists on the lower end of the site. The homes in this area are relatively new and were constructed primarily in the 1960's. The storm sewers are on a separate system with both roof drains and foundation drains connected to it. The roads in the Lake Hills area



URBAN STORM WATER SAMPLING STATIONS MAP

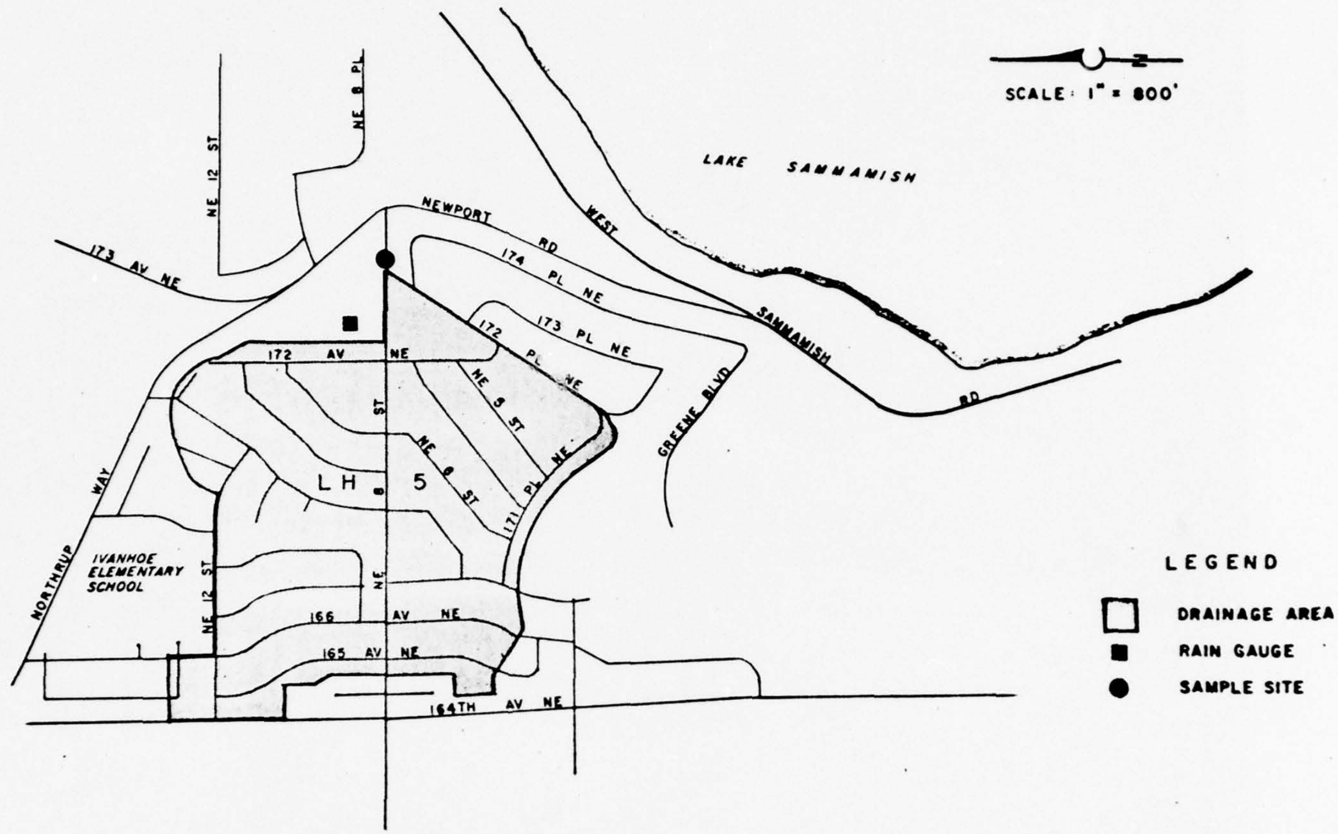
FIGURE I



VIEWRIDGE 1 & 2 (VR1 & VR2)

FIGURE 2

FIGURE 3 VIEWRIDGE ONE DRAINAGE AREA



LAKE HILLS 5 (LH 5)

FIGURE 4

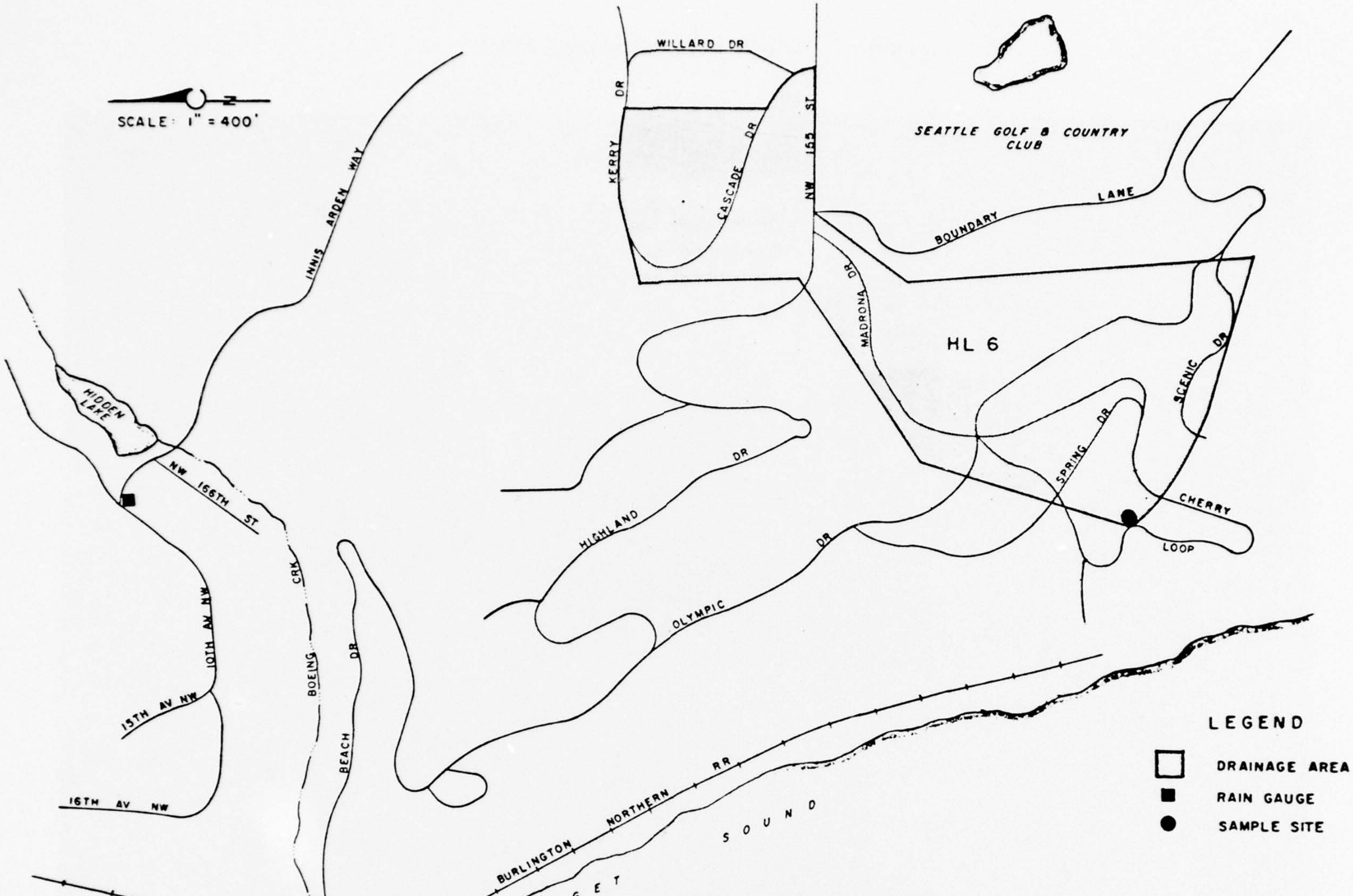
FIGURE 5 LAKE HILLS DRAINAGE AREA

are all paved and equipped with curbs and catch basins. Topographically, a gentle slope exists in the upper portion of the drainage basin which changes to a relatively steep slope at the lower end before draining to the Lake Sammamish basin. The sampling station for this site is on N. E. 8th Avenue, 350 feet west of Northrup Way. A 48-inch catch basin is located at the sample station site which is equipped with 24-inch inlet and exit lines.

The Highlands residential area is located north of the Seattle City limits and was selected as a study site on the basis of its low density single family residential use (Figure 6). The range in lot size in this area is from 1.5 to 7 acres, an extremely low density (Figure 7). The drainage area sampled (HL6) covers 85 acres but contains a total of only twenty homes. The site is a highly wooded park-type neighborhood with second growth trees covering 80 percent of the area. This results in a major percolation of rainfall into the soil and subsequently very little runoff. This area previously contained a combined sewer system which was separated in 1972. The old combined sewer system in this case is now employed as the storm drain system. This area drains in a westerly direction and is relatively steep. The sample site is located 15 feet west of Cherry Loop Road. The manhole at this location is shallow with one 10-inch and two six-inch inlet lines and one 10-inch outlet line. Several springs flow into the storm sewer system producing a small background flow.

MULTIPLE FAMILY RESIDENTIAL LAND USE

The multiple family residential study site (VR2) was selected in an area tributary to the previous single family residential area located in the Viewridge section of Seattle (Figure 2). The stormwater runoff from this site enters the storm drain system downstream from the VR1 site and the sample taken at the VR2 sample station is a combined sample of the two systems. The quantity data and loading factors for the downstream site is thus derived by difference. The VR2 calibration site contains a drainage area of 105 acres with approximately 50 percent single family residences and 40 percent multiple family units (Figure 8). The remaining 10 percent is a typical neighborhood shopping area which includes such businesses as service stations, grocery stores and a laundry as well as the Children's Orthopedic Hospital. Most of the apartment complexes in the area have been constructed recently and, as a result, the roof and foundation drains are connected to the storm drain system. All the streets are paved and contain curbs and catch basins. The major portion of the drainage basin is located on a moderate slope. The sampling manhole is located on the 40th Avenue N. E., 150 feet south of N. E. 45th. The storm drain line is 72 inches in diameter at this location. A sanitary sewer overflow is connected to the storm drain system 360 feet upstream from the sample station. However, no overflow of the sanitary system into the storm drain system occurred during the study period.



HIGHLANDS (HL 6)

FIGURE 6

FIGURE 7 HIGHLANDS DRAINAGE AREA

FIGURE 8 VIEWRIDGE TWO DRAINAGE AREA

COMMERCIAL LAND USE

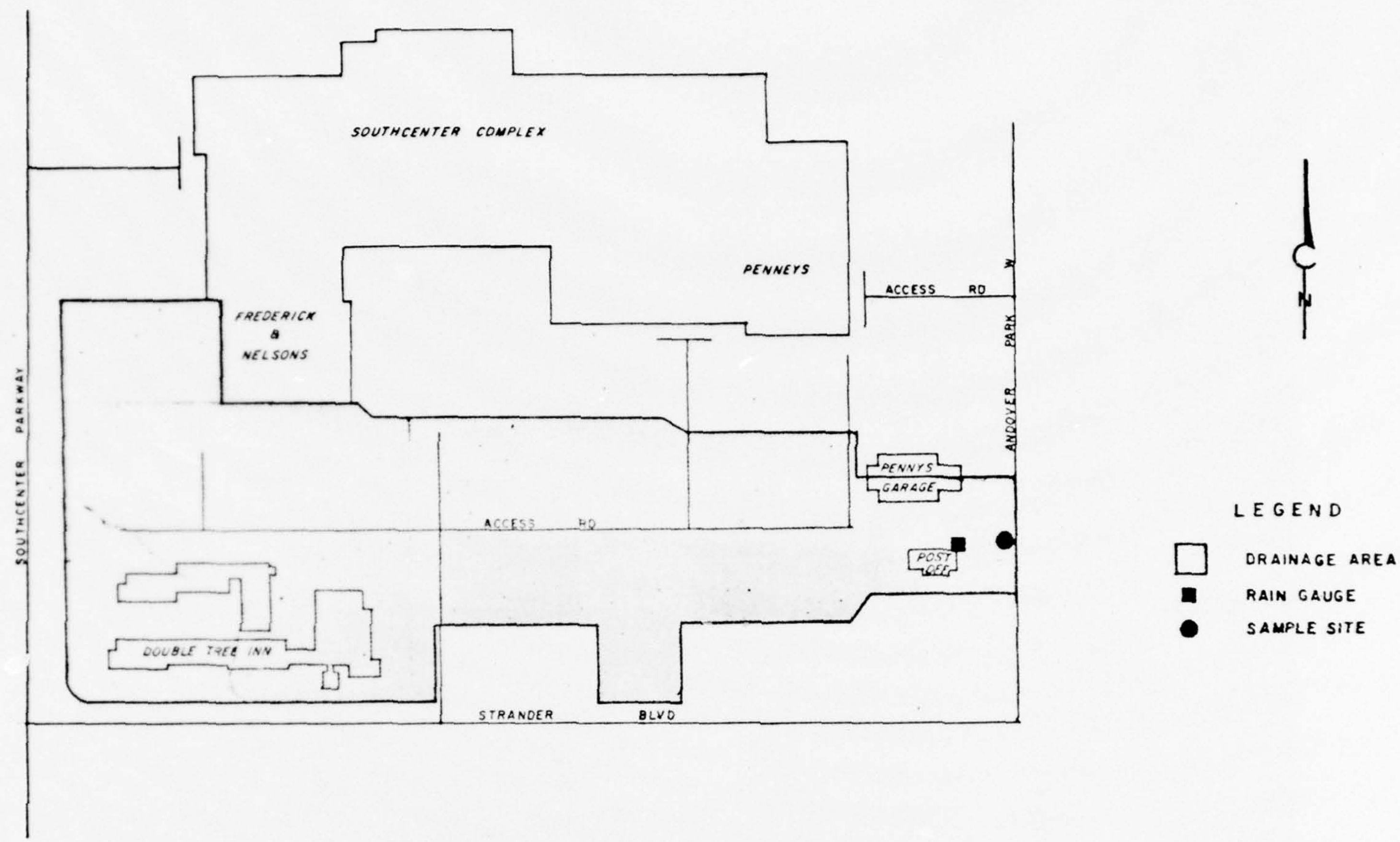
The two sites selected for study as commercial land use types, the Southcenter area and the Central Business District, differ considerably in their characteristics. The Southcenter complex is a typical suburban shopping area located in Tukwila, seven miles south of Seattle. It is a new development and was constructed in the late 1960's. Only a portion of the total shopping area was included in the calibration site (SC4) which covers an area of 24 acres (Figure 9). The site is fully developed with 97 percent of the area covered with an asphalt parking lot and a small number of commercial buildings including a restaurant-motel complex, a postoffice and a service station (Figure 10). Most of the shopping complex, including roof drains, are not tributary to the sample site, but a major portion of the adjacent parking area is. The basin is relatively flat, but drainage is very efficient with rapid runoff and little, if any, ponding. A separate storm drain system exists which drains in an easterly direction. The sampling site is located 150 feet northeast of the Southcenter postoffice with the storm drain line 24 inches in diameter at this point.

In contrast, the Central Business District is 40-60 years old and contains a combined sanitary-storm sewer system. A major portion of the area is covered with commercial buildings with only a small portion covered by paved parking areas. The area selected for sampling(CBD7) is located in downtown Seattle between Western and Third Avenues and between Bell and Virginia Streets (Figure 11). This site contains an area of 27.8 acres and a total of approximately 80 businesses. This includes hotels, wholesale and retail outlets and some light manufacturing (Figure 12). All the streets and alleys are paved with curbs and catch basins. The drainage from the area is relatively good with little ponding. The sampling station manhole is located at the intersection of Western Avenue and Bell Street, just under the Alaskan Way viaduct. The drain line at this site is 18 inches in diameter.

The sampling of the combined sewer system in this area with deviation of results by difference was recognized as a possible source of error based on the much larger background pollutant levels in the sanitary sewer stream. However, a reasonable substitute representing a typical downtown business district could not be located which satisfied the established criteria as well as the present site. The error generated in use of data from the combined system was thus deemed to be less than that which would be incurred by relaxing other areas of site selection criteria.

INDUSTRIAL LAND USE

The only industrial area monitored in the study is located in South Seattle (Figure 13). The site (SS3) is located west of 4th Avenue South and north of South Michigan Street, and is called the Benaroya Industrial Park. It is small in size, 27.5 acres, and contains approximately 30 to 35 manufacturing establishments. These range

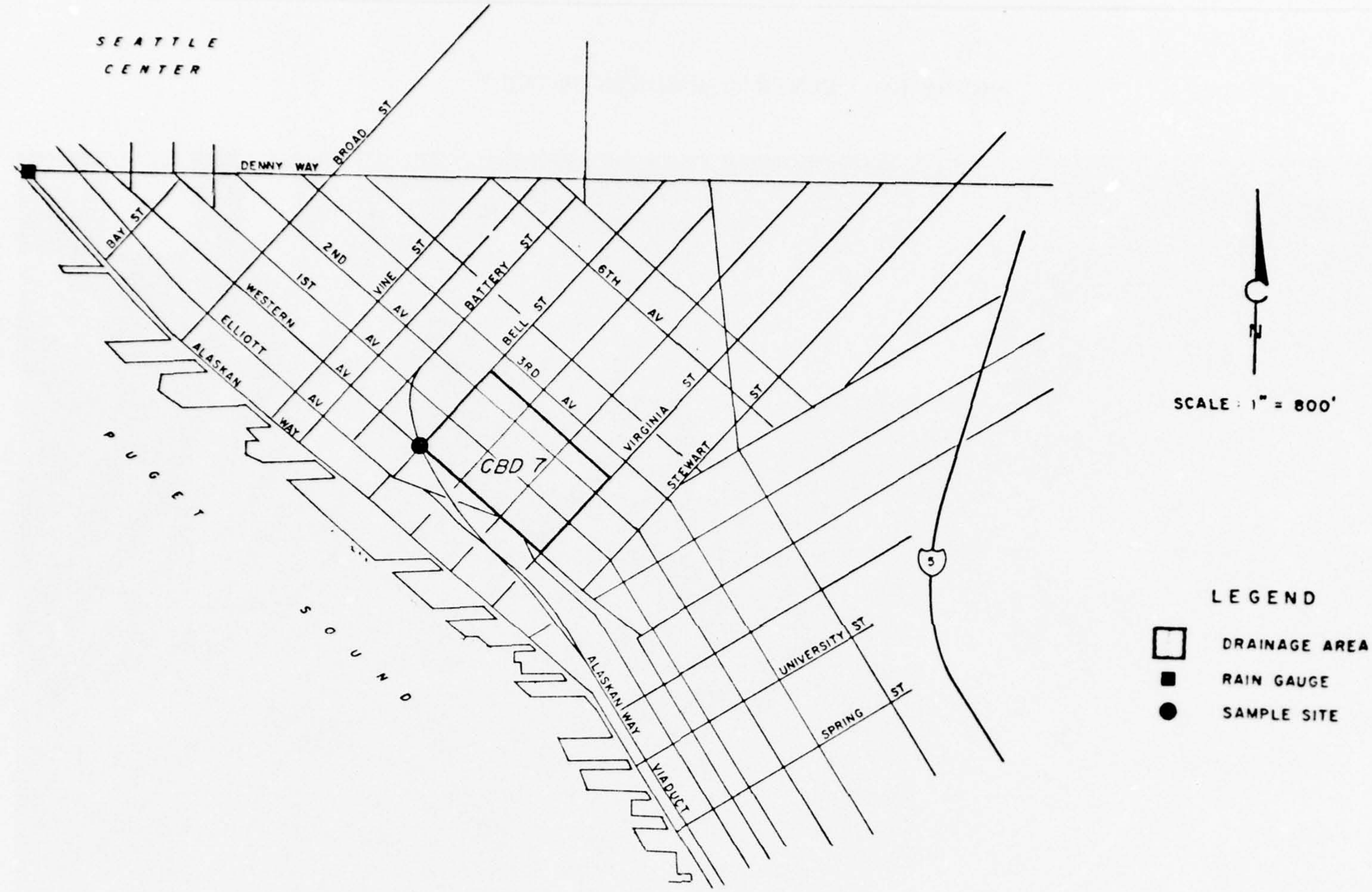


SOUTHCENTER (SC4)

FIGURE 9

FIGURE 10 SOUTHCENTER DRAINAGE AREA

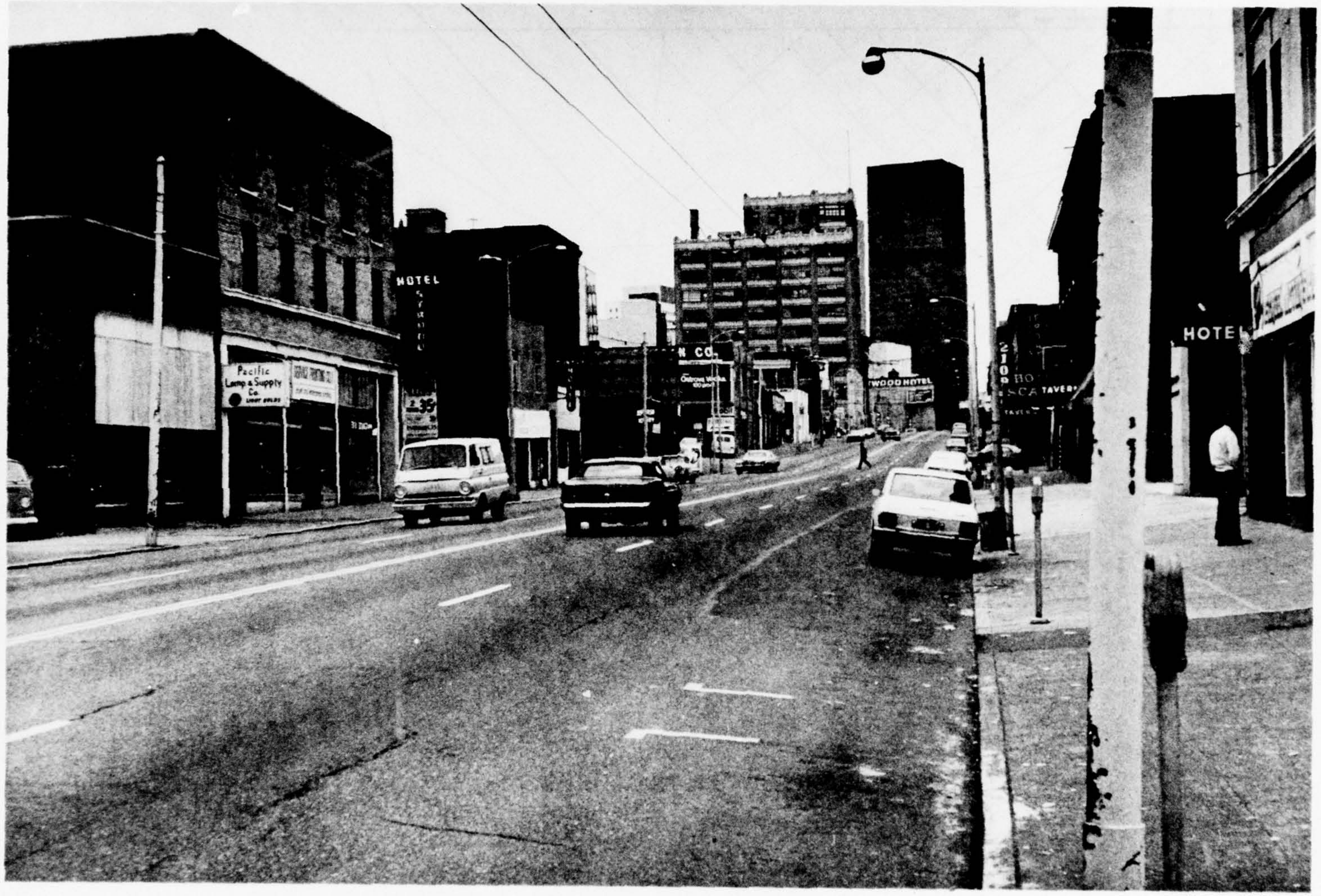
FIGURE 10 SOUTHCENTER DRAINAGE AREA

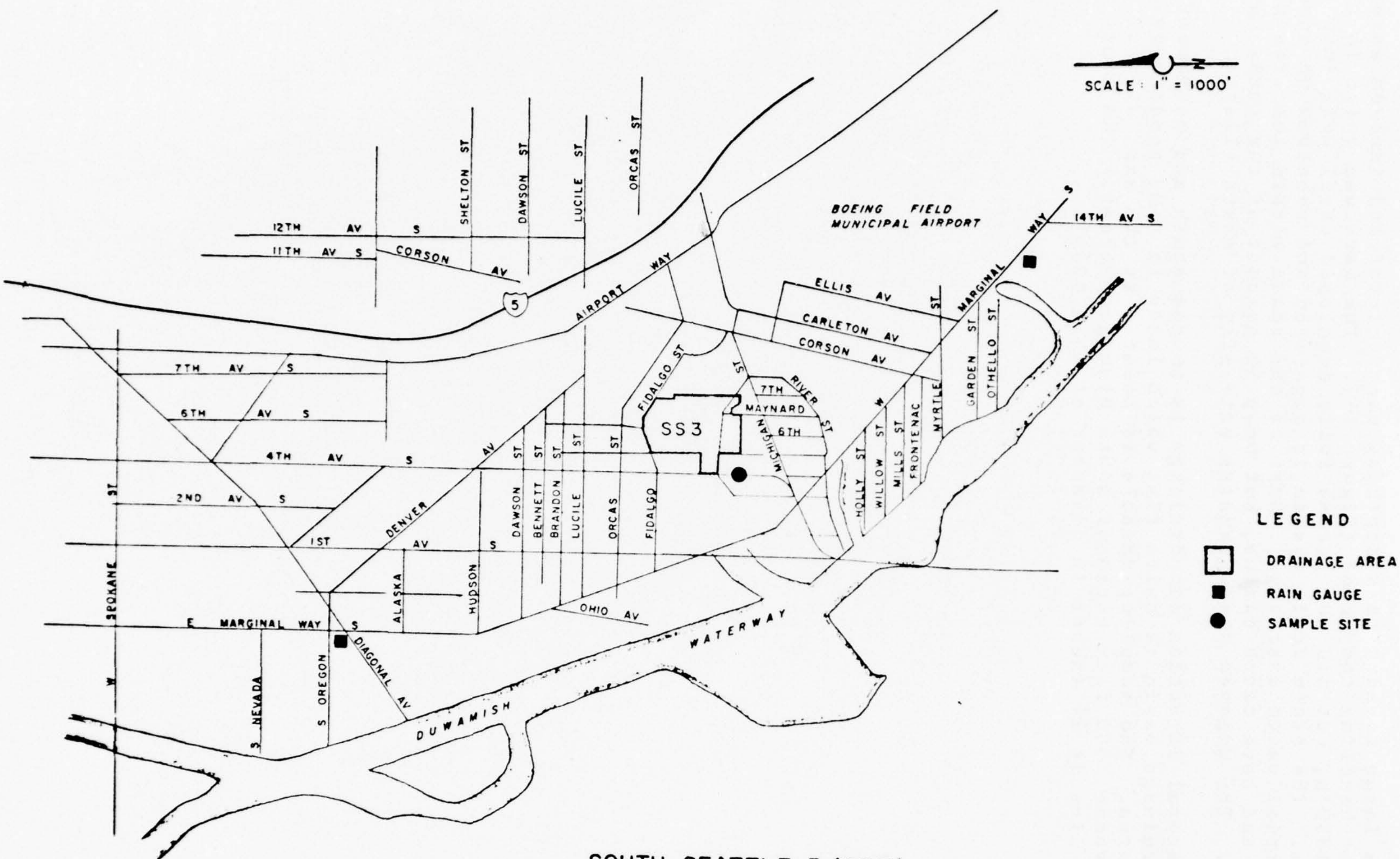


CENTRAL BUSINESS DISTRICT (CBD 7)

FIGURE II

FIGURE 12 CENTRAL BUSINESS DISTRICT





SOUTH SEATTLE 3 (SS3)

FIGURE 13

from a large foundry to a clothing manufacturer and include several freight handling companies (Figure 14). The park was built in the late 1950's, but did not become fully developed until well into the 1960's. The storm drain system is separated and receives no known industrial waste discharge. Most of the roads within the area are paved and have catch basins, but only 50 percent of the roads have curbs. The unpaved roads consist primarily of short alleys.

The general direction for drainage is to the south and southwest. The drainage basin is quite flat which leads to some ponding in this area. The sampling manhole is located at the east side of 4th Avenue, 500 feet north of South Michigan Street. The storm drain line is 24 inches in diameter at this point.

FIGURE 14 SOUTH SEATTLE DRAINAGE AREA

CHAPTER 3

RAINFALL

A manual sampling procedure was utilized in the stormwater quality sampling program because of sample size required and lack of time to design an automatic sampler (see Chapter 5). In order to provide manning of the sample stations prior to any rainfall, an advance warning system was established in cooperation with the Auburn Office of the National Weather Service. They were able to provide continuous surveilance of rainfall conditions utilizing the NWS-FAA radar unit located in Auburn to track the approaching storm fronts. Contact was maintained by telephone with the Weather Service on a 24-hour seven day a week basis for purposes of alerting the crew. Besides notification of impending rainstorms, the National Weather Service was able to furnish information on the approximate time of the arrival of the storm front in Seattle, the probability of rainfall and the probable intensity of rainfall.

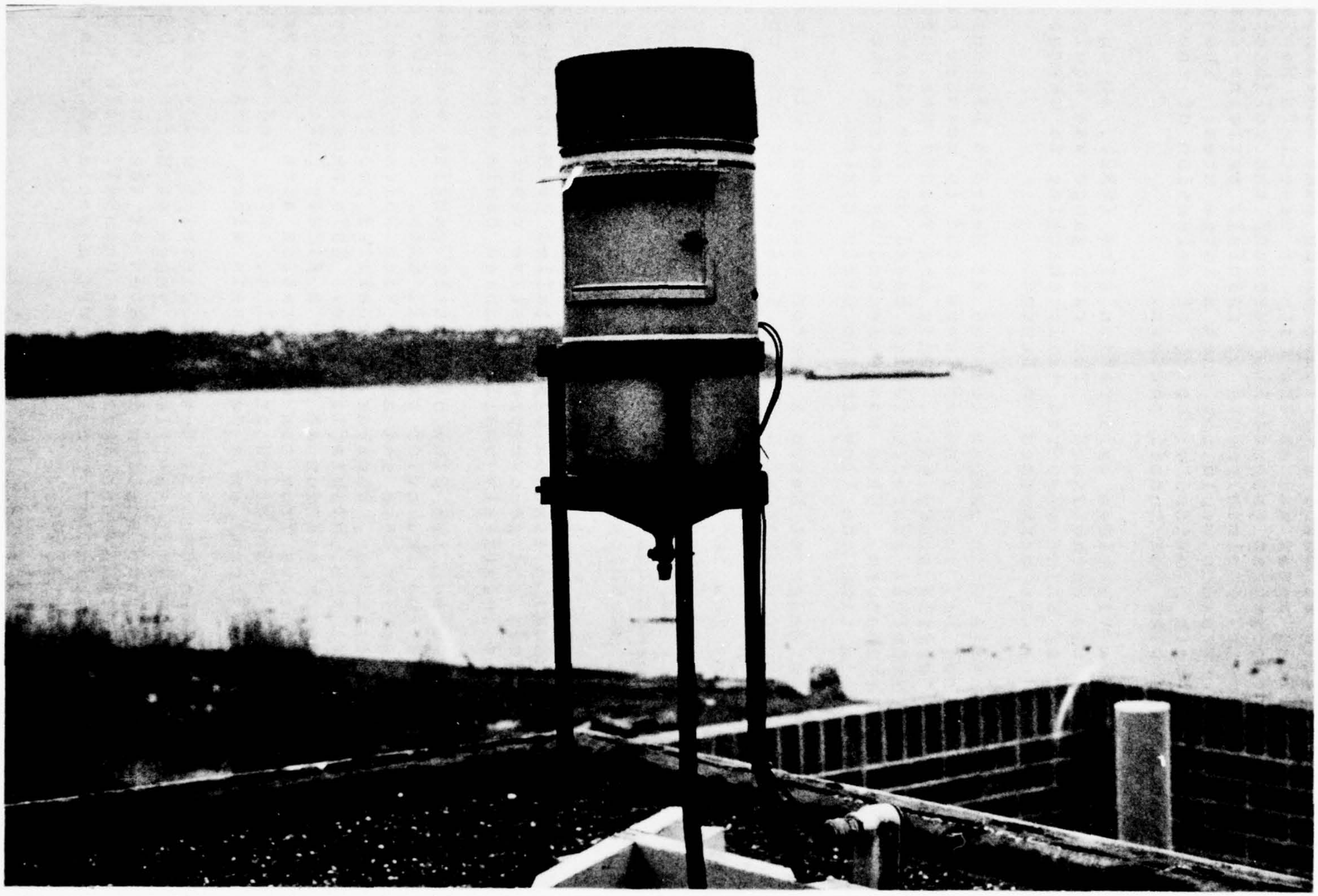
As normal in weather predicting, 100 percent accuracy is hard to achieve. Occasionally, a weak appearing storm front would develop into a heavy rainstorm, the storm of May 25 and 26 being a prime example. More likely was the prediction of a rainstorm which did not develop into its full potential. This produced several false starts resulting in lost time and expense. Despite these difficulties, the warning system provided by the National Weather Service greatly facilitated the sampling program and was invaluable to the successful completion of the study.

RAIN GAUGE LOCATIONS

A total of thirteen gauging stations were used to monitor the rainfall within the calibration areas (Figure 15). Six of the rain gauges were part of a city-wide network maintained by the City of Seattle Engineering Department on a continuous basis. The other seven gauges were either selected from Metro's existing network or installed specifically for the study and were operated and maintained by Metro.

In setting up a gauging system, the existing network (City of Seattle and Metro's) within the proximity of the calibration areas were utilized as much as possible. The pattern of rainfall deviated somewhat within the calibration sites creating some problems with use of data from the existing stations; however, the time constraint for completion of the study precluded establishing a better network. These deviations included a time lag of rainfall peaks and a poor correlation of total rainfall to runoff volumes. The time difference was corrected by selecting the rain gauge stations showing no phase lag where multiple records existed or employing a phase shift in the case of a single record. The poor correlation problem was partially solved by establishing additional on-site recording stations, but a complete rain gauge network was not feasible within the scope of the present study.

FIGURE 15 RAINGAUGE INSTALLATION



Three of the City of Seattle rain gauges are located within the proximity of the Viewridge calibration area and thus were used to monitor the rainfall for the Viewridge One monitoring site. These gauges are located at Metro's Matthews Beach pump station, at the University of Washington and at the City of Seattle's Maple Leaf Reservoir. These gauges essentially surround the calibration site and provide a more complete record of rainfall patterns than a single on-site recorder would for such a large area. The multiple record in this case provided a choice of selection of the record best correlated with the runoff pattern.

In the downstream Viewridge calibration site (VR2), an on-site gauging station was established. The rain gauge was equipped with a 24-hour recorder which required daily checking to change charts while maintenance was performed on demand.

Two City of Seattle rain gauges located at Metro's Diagonal Avenue and East Marginal Way pump stations were used to measure rainfall for the South Seattle study site. Only one record was used to determine the rainfall characteristics based on the direction of travel of the rainstorm. This was selected by noting the record which preceded in time the flow in the drain system.

An existing rain gauge at Metro's Renton Treatment Plant was selected for use in the Southcenter area. This location is only one mile from the site, but the correlation of the rainfall volume to runoff quantity was very low in most cases. For this reason, an on-site gauge was installed immediately adjacent to the sample station. Considerable gaps in the data resulted from malfunction of the new gauge which necessitated continued use of the Renton data until August 28, 1973, at which time the new gauge was functioning properly.

The Lake Hills gauging station was installed by Metro in the drainage area being sampled, and good representative results of the rainfall patterns within a relatively small drainage basin were assumed.

In the Highlands area, two City of Seattle gauging stations were used initially as the source of rainfall data. These two stations were located at Haller Lake and at the Rich Whitman school. The data from these stations, however, correlated poorly with the runoff characteristics at the calibration site. This necessitated installing an alternate station at Metro's Hidden Lake pump station approximately 0.8 miles from the calibration site. The recorder was installed at this location on April 4, 1973, and has been maintained by Metro personnel on a daily basis since that date.

Rainfall data for the Central Business District study area was obtained from the City of Seattle rain gauge at Metro's Denny Way pump station. The pump station is located at the intersection of Denny Way and Elliott Avenue East, about one-half mile north of the sample area. No particular problems were associated with use of the data from this station.

In the selection of alternate sites for the rainfall gauging stations, various criteria were used. The most critical of these was a close proximity to the calibration site in order to provide representative rainfall data. The characteristics of the site were also of importance since the location had to be an open area to permit maximum collection of rainfall. Such characteristics included the absence of tree limbs sheltering the gauge or nearby buildings blocking the blowing rain. In some cases, these factors were not always obtainable. For example, at the Highlands' site, the rain gauge had to be located a greater distance from the drainage area than desirable. Another problem was encountered in obtaining permission to install gauges at locations best suited for rainfall monitoring. Since the strip charts for the Metro gauges had to be changed daily, some inconvenience for property owners was possible, but was held to a minimum. Taking all factors into consideration, the present locations of the rain gauges are the most reasonable under the circumstances. However, the problems encountered point out the necessity of establishing the gauging stations as close to the monitoring sites as possible in order to obtain the most representative data.

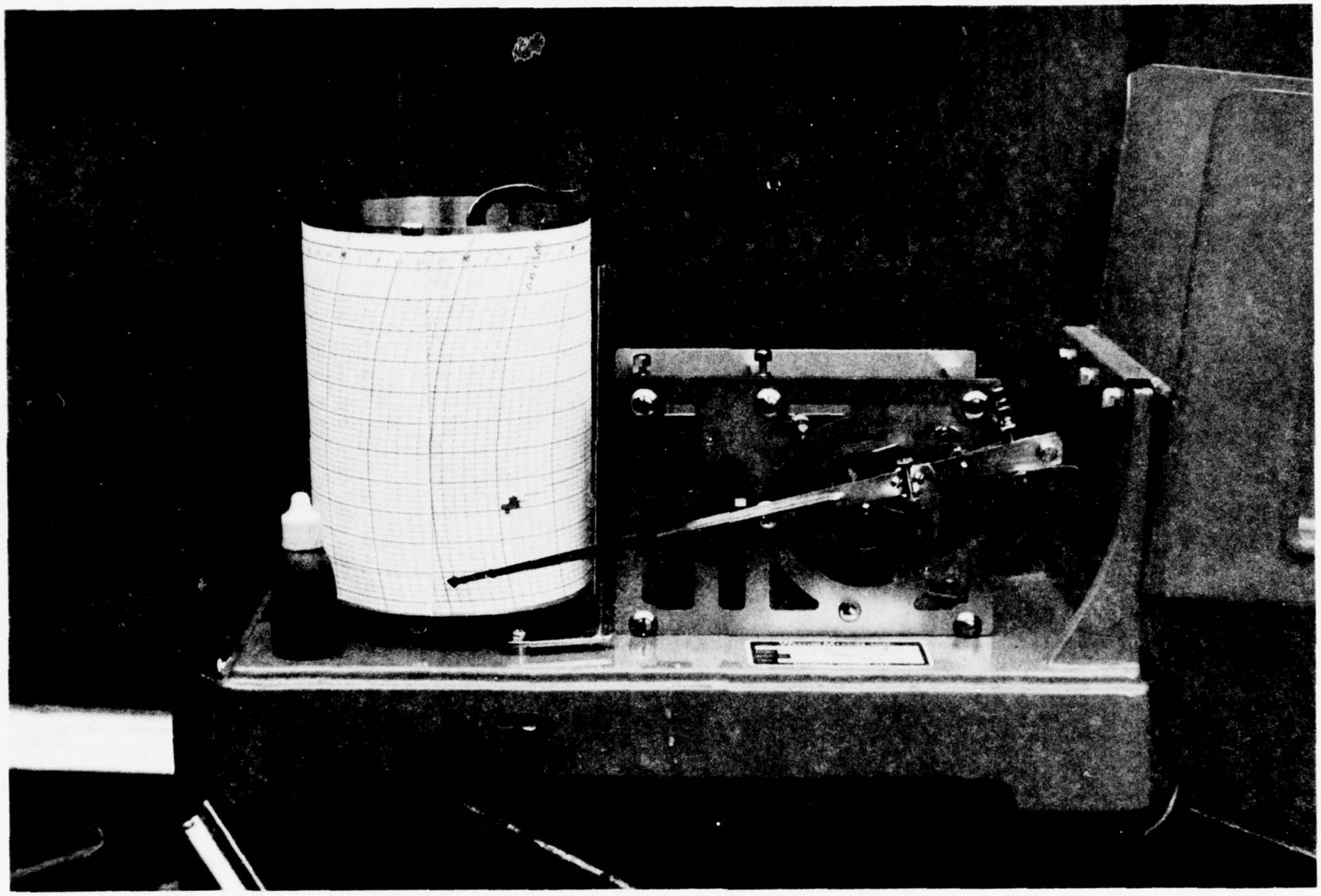
EQUIPMENT

As note previously, two different data sources were used in the Urban Storm Drainage Study - rain gauges owned and operated by the City of Seattle, and those installed and maintained by Metro. The rain gauges in both cases were the tipping bucket type manufactured by Stevens and equipped with rainfall detector and event recorder (Figure 16). The rainfall volumes were recorded in increments of 0.01 of an inch. The rain gauges, in general, were found to be very reliable and easily maintained. However, the daily changing of the strip charts on those gauges installed by Metro proved to be a very time consuming job.

The Metro and the City of Seattle rain gauges differed only in the type of mechanism used to record the time interval for events. The City utilizes a recording device that provides for a continuous scan at one minute intervals with each rainfall event being recorded within the specific time of occurrence. The events are recorded on magnetic tape which is subsequently interpreted by an automatic data processing system. Metro uses the normal 24-hour strip chart recorders.

The time interval in this case can be interpreted only to five-minute increments and the data must be manually interpreted for processing. There is an obvious advantage to the City of Seattle system, however, the time constraint in the present study precluded establishing such an automatic recording system at other locations. The cooperation of the City of Seattle Engineering Department in supplying rainfall data to Metro, which often required special handling, contributed greatly to the success of the program and saved considerable time and expense.

FIGURE 16 STEVENS RAINFALL RECORDER



RESULTS

The rainfall data collected by the City of Seattle was processed by the City on a monthly basis, and was transmitted to Metro in the form of a computer printout sheet. This sheet contained information on the day, hour and minute of each rainfall event as well as the accumulated volume for each storm. A moving accumulation as well as hourly, daily and monthly accumulated totals were recorded, but not used, in the present study. This data was tabulated by extracting the accumulated volumes over each 15-minute interval and graphing the accumulated volumes against time along with runoff volumes over the same time interval. Metro's rainfall records were processed in the same manner with the exception that the data had to be extracted from the strip charts and summarized manually before graphing. Each individual strip chart in this case covered only a 24-hour interval in contrast to the monthly summary from the City. Although both records presented a continuous record of rainfall, the advantage of the summary sheet is obvious.

The daily rainfall volumes for all gauging sites for the period of February to June, 1973, are presented in Appendix 1 with the days on which samples were collected for quality measurement denoted. The rainfall totals for the seven urban storm drainage sampling areas varied considerably from site to site, not only with respect to intensity, but also with time and within a given period. In some cases this difference is noticeable between rain gauges monitoring a single calibration site as in the case of the View-ridge One area. For example, the rainfall on February 25 and 26 produced totals of 0.74 and 0.69 inches at Matthews Beach, while the corresponding values at the University of Washington station were 0.55 and 0.70 inches respectively. On the 25th, a substantial difference exists between the two stations while almost identical totals were recorded on the 26th. On April 26, it rained 0.42 inches at Matthews Beach, but only 0.13 at the University of Washington. On August 13, 0.06 inches of rain was recorded at Matthews Beach, but none at all at the University or the Maple Leaf Reservoir stations.

Obviously the greater separation of distance between stations, the greater the variation to be expected. This is borne out by some of the striking differences exhibited between the Southcenter and Hidden Lake gauging stations. Between February 25 and March 3, a much larger rainfall was recorded at the Highlands than at Southcenter totaling 2.12 inches and 1.46 inches, respectively. On April 15, 0.19 inches of rain fell at Highlands and 0.64 inches were recorded at Southcenter.

Such comparison can be drawn between all seven calibration areas, which demonstrates the wide variance in rainfall patterns. This variance was noted even for gauging stations within a radius of two to three miles. This is a significant factor in the present study where gauging stations in some cases were located at the outer

edge of the calibration area, e.g., Viewridge One. A large number of rain gauges within the study area and in as close a proximity as possible to each other is an important factor for providing rainfall data that is representative of the area being monitored.

Table 1 lists some relevant parameters that were calculated for each of the six storms sampled for quality analysis. The areal variation in rainfall intensity and volume as well as duration of individual storms is demonstrated by the summary figures. Variations up to 300 percent are noted between the various sample sites for all three parameters listed.

TABLE 1

SUMMARY OF RAINFALL DATA

STORM	VR1	VR2	SS3	SC4	LH5	HL6	CBD7
2/14/73							
Duration (hrs)	6.25	5.75	-	6.25	-	-	-
Rainfall (in)	0.07	0.07	-	0.12	-	-	-
Intensity (in/hr)	0.011	0.012	-	0.019	-	-	-
3/10/73							
Duration (hrs)	4.5	5.25	7.0	5.75	5.25	4.00	4.25
Rainfall (in)	0.26	0.33	0.40	0.49	0.39	0.38	0.29
Intensity (in/hr)	0.058	0.063	0.057	0.085	0.074	0.095	0.068
3/16/73							
Duration (hrs)	2.5	3.5	4.25	2.75	2.25	2.5	2.0
Rainfall (in)	0.05	0.06	0.08	0.04	0.06	0.07	0.06
Intensity (in/hr)	0.020	0.017	0.019	0.014	0.027	0.028	0.030
6/6/73							
Duration (hrs)	4.5	5.0	6.0	5.0	5.0	2.25	4.0
Rainfall (in)	0.11	0.09	0.18	0.28	0.27	0.06	0.08
Intensity (in/hr)	0.024	0.018	0.030	0.056	0.054	0.027	0.020
8/16/73							
Duration (hrs)	4.75	3.00	5.00	4.25	4.5	-	2.8
Rainfall (in)	0.10	0.10	0.09	0.07	0.05	-	0.08
Intensity (in/hr)	0.021	0.033	0.018	0.016	0.011	-	0.028
9/19/73							
Duration (hrs)	7.25	9.00	9.25	10.8	9.25	4.25	7.47
Rainfall (in)	0.33	0.32	0.32	0.36	0.27	0.31	0.29
Intensity (in/hr)	0.046	0.036	0.034	0.033	0.029	0.073	0.039

CHAPTER 4

RUNOFF QUANTITY

The quantity of urban stormwater runoff was monitored at each calibration site on a continuous basis. The total flow was computed in each case from flow depth measurements and calculated flow velocities. This approach was selected over direct velocity measurement because of the relatively trouble-free operation with very little loss in accuracy and reliability. As a result, quantity measurements are continuous over the total study period with some exception. Subsequent measurements have further extended this record to over a full year's period, i.e., February, 1973 to March 1974.

Level recorders were used at all sampling stations to provide the depth recording of stormwater flow. The recorders installed were the Arkon Model 63 TN, a portable unit (Figure 17). The measuring system consisted of a gas bubbler tube for sensing water depth, a transducer for converting the pressure dependent signal to a millivolt signal and a 10-inch strip chart for logging the millivolt signal. The chart for the recorder is powered by a hand-wound seven-day clock while the remainder of the equipment is powered by dry cell batteries. The nitrogen employed as the bubbler gas was supplied from a cylinder.

The units with two exceptions were housed in special fiberglass shells supported above ground on a steel pole to which the nitrogen cylinder was attached and through which the bubbler tubes were run (Figure 18). The remaining two units were housed in steel cabinets. Although the strip charts did not require changing for several months, the recorders were serviced on a twice-a-week basis to perform other tasks, such as adding ink, winding the clocks, and checking the nitrogen gas supply. Field technicians were able to maintain the equipment in good working order while major repairs required the services of specialized personnel.

CALIBRATION

An empirical calibration was performed to compute stormwater quantity from depth of flow. This involved two field measurements, the slope of the storm drain line and the velocity of the stormwater flow for different flow depths in each system. In the latter measurement, two manholes were used which were located a known distance apart. Dye was dropped into the upstream manhole and its time of travel to the lower manhole was measured for each designated flow depth. The velocity was then calculated from the collected information.

Manning's equation was used to relate the depth of water in a pipe to the quantity of flow. With measurement of the slope and radius of the drain line, and the depth to velocity relationship, all but one of the variables in Manning's equation is known, i.e.,

$$Q = \frac{1.486}{N} \times (R^{2/3}) \times (S^{1/2}) \times A$$

FIGURE 17 ARKON FLOW RECORDER

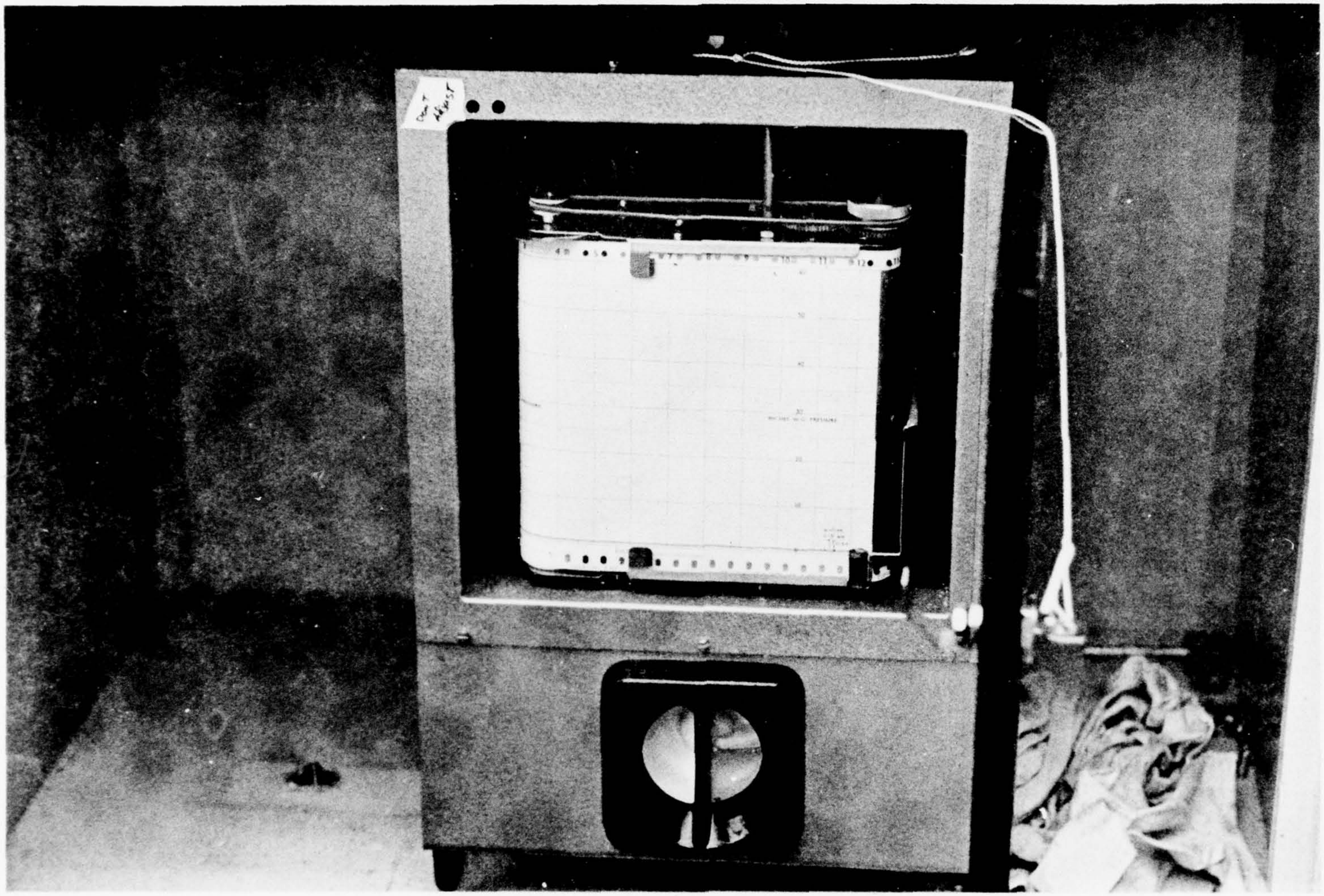


FIGURE 18 FLOW RECORDER INSTALLATION

The quantity of water, Q, is equal to VA, the product of the velocity and the cross sectional area; S is equal to the slope in feet per foot; and R, hydraulic radius, is known from the depth. The frictional factor, N, is the only unknown variable which can be solved for by use of the field data. A nomograph of depth versus quantity is then developed for each system ranging from zero to maximum depth of the line.

LIMITATIONS

The physical arrangement of the system was found to be a limiting factor in accurate flow measurement with the bubbler system. The major problems in this respect were encountered at three stations; Southcenter, Lake Hills and Highlands. The velocity of the stormwater flow at these three sites were found to be unusually high at times creating a problem in depth measurement. The source of the problem was related to the stormwater rushing past the bubbler tube creating a Venturi effect. To alleviate this problem, V-notched wiers were installed at the Southcenter and Lake Hills stations and a Cipolletti wier was installed at the Highlands Station on April 23 and 24, 1973. The wiers reduced the velocity of flow although some problems persisted in the calibration data and in conversion of the depth data to flow. This necessitated revisions of the data before final edition.

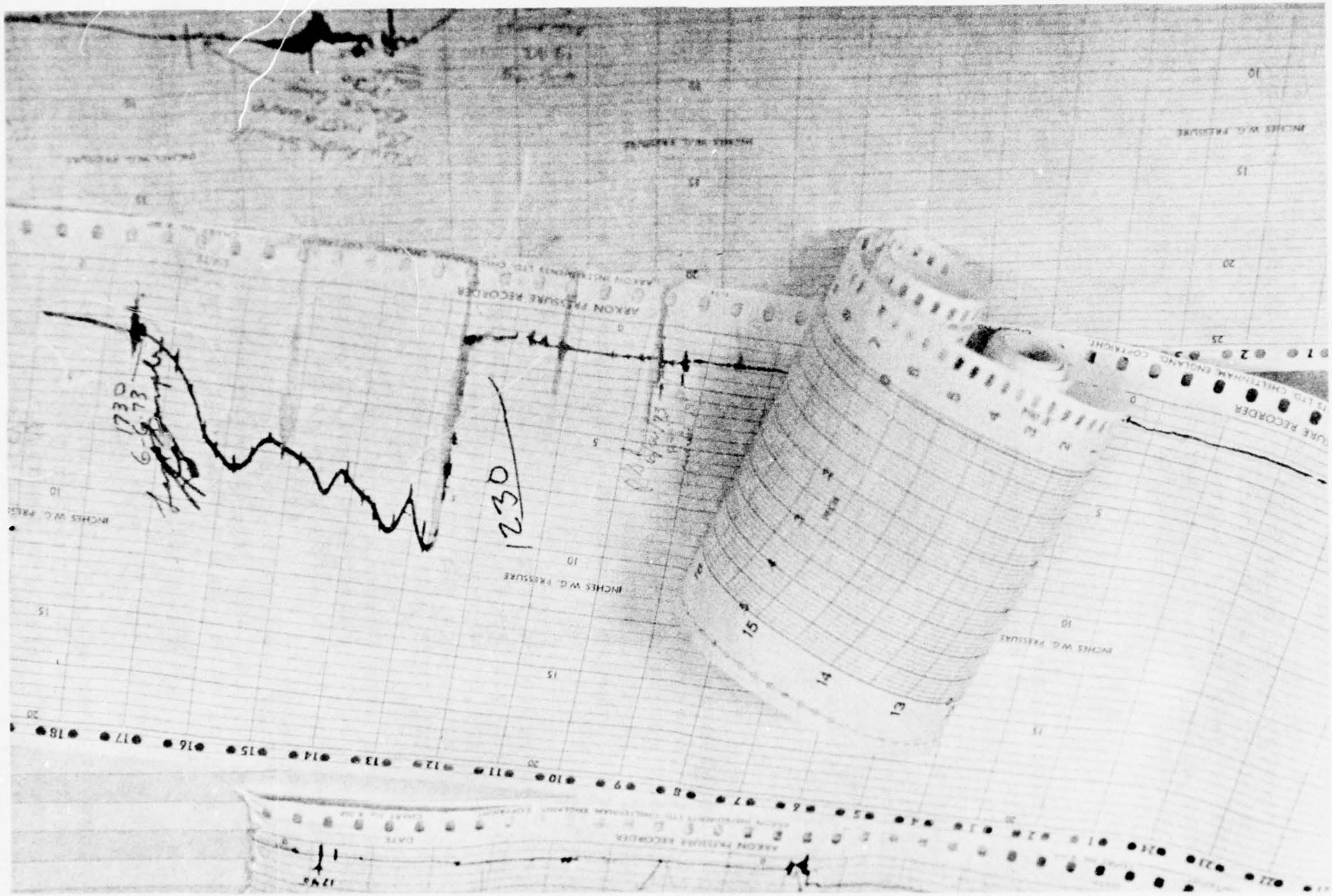
Malfunctions in the equipment were minimal, usually being confined to inoperative clocks or improperly installed charts. If the system is maintained adequately, the loss in flow data from breakdown is kept to a minimum. In the presence of a large amount of floatable material such as rags and paper, a problem can be encountered with hangup of these materials on the bubbler tube, but this problem did not arise.

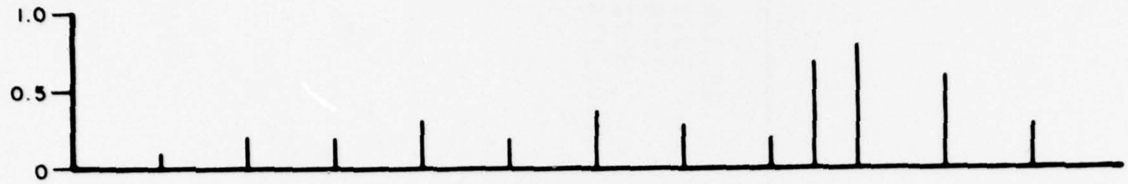
Another limiting factor was the time consumed in calculating flow volumes. Processing the flow charts involved scanning the charts for stormwater events, cutting out each storm record after marking it with the date and location (Figure 19), and calculating the volume of flow for each 15-minute interval using the table developed for conversion of depth to volume. A continuous graph of storm runoff quantity versus time was constructed using interpolated values between each 15-minute point. In cases where a maximum or minimum in the original chart occurred between two 15-minute intervals, these points were also included in the conversion. An example of a finished hydrograph appears in Figure 20.

RESULTS

By integrating the developed graph, the volume of stormwater runoff resulting from a specific storm was calculated. These calculations were performed for all storms on record and the results appear in Table 2. These figures were then compared to the total runoff possible from the monitoring site for the purpose of calculating the percentage of runoff. The total volume of runoff possible was derived from the inches of rainfall times the total collection area.

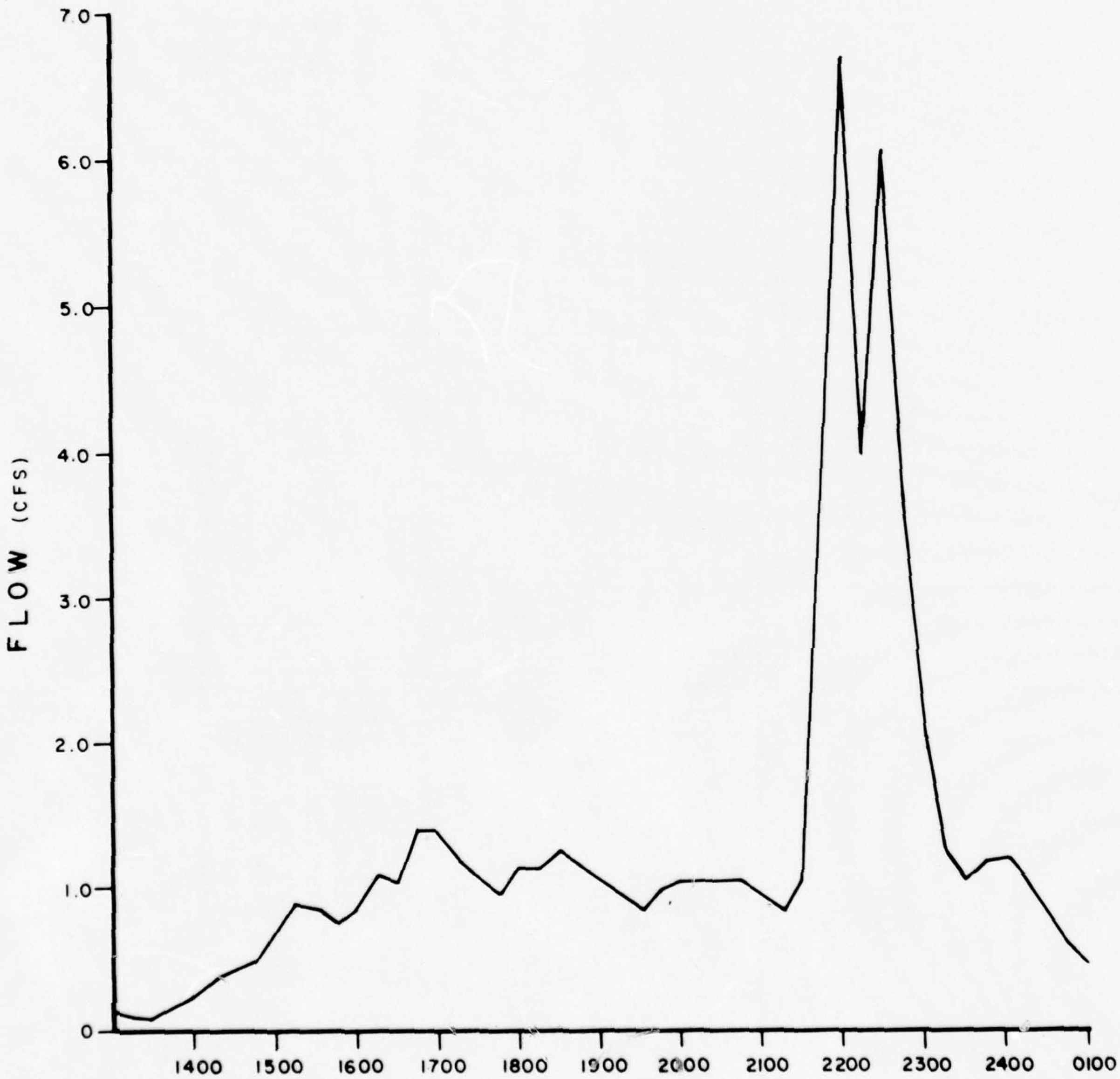
FIGURE 19 FLOW RECORDS





RAINFALL IN INCHES

SOUTH CENTER 4
SEPT. 23, 1974



HYDROGRAPH OF STORMWATER RUNOFF
FIG. 20

TABLE 2

STORMWATER RUNOFF VOLUMES

Date	Volume, cubic feet						
	VR1	VR2	SS3	SC4	LH5	HL6	CBD7
Feb. 14	8612	12,848	-	1627	-	-	-
Mar. 10	130,797	250,848	21,526	21,046	46,993	8377	25,230
Mar. 16	19,538	19,790	1702	1209	7072	6966	2819
June 6	13,584	22,059	3725	14,848	4794	367	7506
Aug. 16	5547	8838	376	7618	5767	-	8972
Sept. 19	27,307	46,087	44,902	18,630	19,711	1078	13,874

TABLE 3

MEAN PERCENTAGE OF STORMWATER RUNOFF

Viewridge (VR1)	13.6
Viewridge (VR2)	33.8
South Seattle (SS3)	34.9
Southcenter (SC4)	53.9
Lake Hills (LH5)	7.4
Highlands (HL6)	4.9
Central Business District (CBD7)	64.6

The percentage of runoff based on a single mean for all storms is recorded in Table 3 for each calibration site. These values ranged from 4.9 to 64.4 percent, which is lower than expected. This is due in part to the unusually light rainfall which occurred during this period, although type of storm, rainfall volume and intensity, season, ponding and other types of interception also affect the percentage of runoff.

There is a large variance in the percentage of runoff between the various calibration sites which correlates well with land use patterns. The highest percentage of stormwater runoff are, as expected, from Southcenter and the Central Business District as a result of the high percentage of impervious surfaces at these two sites. The Highlands and, to a lesser degree, Lake Hills are heavily wooded and a major part of the rainfall percolates into the soil resulting in the lowest percentage of runoff.

The difference in percentage of runoff (2.5 times) between the two Viewridge areas was unexpected since these two areas are adjoining and similar in many respects. However, there are several reasons for this difference. First, the VR1 area is mostly a single family residential area. A larger percentage of each lot's surface in the VR1 area is covered by lawn or garden which diminishes the potential for runoff. Further, many of the downspouts in the VR1 area are connected to the sanitary sewer resulting in a lower apparent runoff. As noted previously, the roof drains have been estimated to comprise approximately 30 percent of the runoff surface, which represents a relatively substantial influence on runoff volumes. This contrasts with minimum vegetated areas within the apartment complexes and roof drains which are connected to the storm drain system.

Similar factors apply to the other study areas. Lake Hills, with a low runoff potential, is mostly single family dwellings with relatively large yards. South Seattle is largely paved or covered with large buildings and demonstrates a higher potential for runoff. However, the presence of unpaved areas and ponding contributed to a lower percentage of runoff than anticipated. This correlation of runoff to area of impervious surface demonstrates the close relationship between land use patterns and percentage of runoff.

CHAPTER 5

QUALITY MEASUREMENTS

The determination of the quality of the urban stormwater runoff involved the analysis of 29 different parameters. The selection of parameters was based on the need to define such problem areas as oxygen demand, nutrient loading, sanitary significance, solids loading, heavy metal contamination, etc. Not all the parameters were capable of being modeled, but the information collected was felt to be important to the overall definition of stormwater quality. The list of parameters selected are presented in Table 4.

TABLE 4

QUALITY PARAMETERS

Physical - temperature, pH, conductivity, turbidity

Oxygen Demand - dissolved oxygen, BOD, COD

Nutrients - ammonia, nitrate, nitrite, organic nitrogen, total hydrolyzable phosphorus, ortho phosphate

Inorganics - sulfate, chloride

Hexane Extractable - oil and grease

Heavy Metals - mercury, copper, zinc, lead, chromium, cadmium, arsenic and iron

Solids - suspended, settleable, total dissolved

Coliforms, total, fecal

SAMPLING PROCEDURES

A manual sampling procedure was utilized for collecting the stormwater runoff samples which consisted simply of taking a grab sample at each specified time interval. Although this approach was less desireable than automatic sample collection, development of an automatic sampling system was not possible because of the time constraint involved in completion of the study. The size of sample required (two gallons) was also a serious constraint in development of an automatic sampler because of the tremendously large storage area required to handle the total volume generated during a storm.

As noted previously, the use of manual sampling procedure required the development of a warning system to allow the sampling crew sufficient time to reach the sampling site prior to the beginning of the storm. A study coordinator was selected to maintain continuous contact with the National Weather Service and to make the decision on calling out the sampling crew. His decision was based on the probability of rainfall, generally in excess of 50 percent,

and the predicted rainfall intensity. A seven-man crew was dispatched on callout, one to each site, and a two-man crew was used for coordination and sample pickup. The sampling crews were, in the majority, field or laboratory technicians with prior training and experience in water quality sampling. During the initial portion of the sampling program, Metro crews handled this responsibility. In July, 1973, a consulting firm, CH2M, (Cornell, Howland, Hayes & Merryfield) was hired to handle the sampling with Metro maintaining the responsibility for program coordination and analyses.

All seven monitoring sites were manned simultaneously during a storm to facilitate correlation of the data. This approach dictated that only those storms producing an areawide rainfall at each site could be sampled. The large number of samples reaching the laboratory at one time as a result required the placing of an equal number of laboratory personnel on callout to provide immediate analysis of the potentially degrading constituents. Such analyses were normally completed within a period of three hours after collection. Samples not requiring immediate attention were stored.

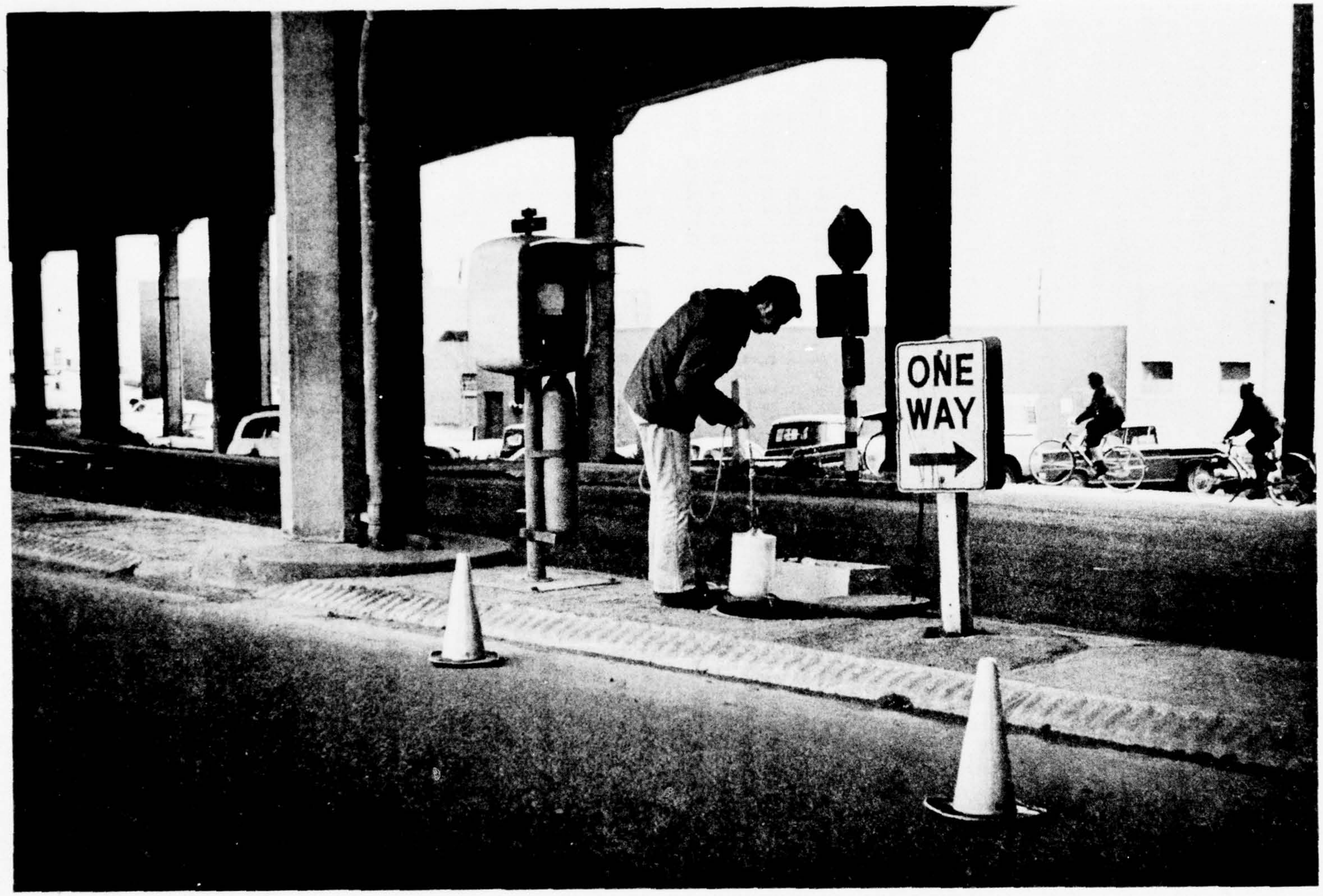
The container used for sample collection was a bucket fabricated from a two-gallon Nalgene bottle with a spigot at the bottom. The spigot was equipped with a rubber hose and a pinch clamp to facilitate drawing a dissolved oxygen and a coliform sample. The bucket was lowered through the manhole on a length of rope and a sample was dipped from the stormwater flow (Figure 21). The coliform sample bottle was filled first by purging the sample hose and then filling the bottle, taking care to avoid contact with the hose.

The dissolved oxygen sample bottle was filled by inserting the rubber hose into the bottle and gently releasing the pinch clamp until a steady stream resulted, carefully avoiding any aeration. After sufficient purging of the bottle, the sample tube was withdrawn and the sample was immediately inoculated with manganous sulfate followed by an alkaline iodide solution in accordance with the modified Winkler method.

The last samples to be taken were two bulk samples which were stored in two-gallon polyethylene containers for use in making the remainder of the laboratory analyses. Temperature measurements were made on site with a mercury thermometer and recorded along with the sample time.

When a background flow existed in the storm drain line, a sample of the flow was taken prior to the beginning of the storm. A sample of the stormwater was then collected at the beginning of the flow and at 15-minute intervals thereafter. Although a shorter time interval was desireable, the 15-minute interval was selected as a matter of practicality. Shorter sampling intervals, while providing a better description of quality changes with time, would have produced an unmanageable number of samples. This, in turn, tends to decrease the reliability of results because of the need for rapid sample turnover. Longer intervals are not desireable from a modeling standpoint

FIGURE 21 MANUAL SAMPLE COLLECTION



since inadequate correlation of quality with time would result.

When the flow dropped to zero or previous background levels, sampling was discontinued until the rainstorm commenced again or it was apparent that the end of the storm had been reached. All collected samples were transported to the laboratory within a reasonable length of time. The background and initial samples were brought to the laboratory within one to three hours after collection while subsequent samples were picked up at three-hour intervals. For the most part, the samples were not refrigerated or preserved for transport to the laboratory. This was based on the fact that air temperatures during a major portion of the study were sufficiently low to prevent any substantial deterioration of the samples. During the spring and summer season, however, the coliform samples were chilled with ice to prevent any change in bacterial count.

LABORATORY PROCEDURES

All of the stormwater samples collected during the study were analyzed in Metro's Water Quality Laboratory. The laboratory is equipped with the normal type of instrumentation required for water quality analyses. This includes a perkin Elmer 303 atomic absorption spectrophotometer for heavy metal analysis, and a Technicon Autoanalyzer for automated nutrient analyses. The staff performing the analyses consisting of chemists, biologists, bacteriologists and technicians, are all qualified and experienced in performing the analyses required for the urban drainage study.

As noted, it was not possible to analyze for all parameters immediately, which necessitated the preservation of certain samples before storage. The methods used to preserve the samples are listed in Table 5.

The large number of samples involved required a compromise on the number of samples to be analyzed. This resulted in compositing some of the samples based on flow. The procedure for compositing was designed around the two areas of major interest in regard to quality changes with time, i.e., the initial portion of the storm and the period of maximum flow if this differed from the intial peak. As the flow levels off and starts to decline, the concentration levels become more uniform and the importance of analyzing every sample individually declines. Samples were composited therefore after the first hour of the storm, unless flow was still increasing and after the second peak flow if one occurred. Compositing was not carried out during the two periods of major interest. The aliquot for each composite sample was assumed to be representative of the total time period over which the samples were collected.

TABLE 5

SAMPLE STORAGE METHODS

Ammonia, nitrite, nitrate, orthophosphate - refrigerated at $4^{o}C$, average length of storage 2 to 10 hours.

Kjeldahl nitrogen - preserved in sulfuric acid and refrigeration at $4^{o}C$, storage 1 to 5 days.

Hydrolyzable phosphorus - preserved with chloroform and refrigeration at $4^{o}C$, storage 4 to 48 hours.

Heavy metals - preserved in nitric acid, storage 1 to 5 days.

Solids - no preservation, 4 to 48 hours storage.

BOD - preserved by refrigeration at $4^{o}C$, 2 to 10 hours storage.

COD - preserved in sulfuric acid, 1 to 2 days storage.

Coliforms - preserved by refrigeration at $4^{o}C$, 2 to 10 hours storage.

Chloride - no preservation, 1 to 4 days storage.

Sulphate - no preservation, 1 to 4 days storage.

The two-gallon bulk samples were split into over twenty smaller samples with care having to be taken to insure that each aliquot was representative of the bulk sample. Vigorous mixing of the bulk samples was carried out before extracting an aliquot in order to provide homogeneity of the solids material. In cases where both the raw stormwater sample and its supernatant were analyzed, the sample was thoroughly mixed before withdrawing the raw portion. The remaining sample was allowed to settle for an hour, and the supernatant was then decanted from the solids portion. The methods used for the analyses of the stormwater runoff samples are listed in Table 6.

DATA CALCULATIONS

The mean concentration of each constituent for an individual storm was calculated by dividing the mass contained in the runoff for the entire storm by the total volume of runoff (Equation 1). This included correction for background contribution. Direct averaging of concentration values was not considered to be valid in this case because of the bias resulting from the different length sample periods. The mean concentration values over the total study period was then calculated from the sum of the means for individual storms.

$$(1)\ \text{Mean Concentration} = \frac{CiViTi - B\ (\ Ti)}{(ViTi)}$$

where Ci - Concentration, i th interval
Vi - Volume of flow, i th interval
Ti - Time of i th interval
B = Background loading, mass per unit time
N = Number of sample intervals after compositing

The washoff loading factor in pounds/acre/day for each constituent was calculated by dividing the total mass generated in a particular storm by the area of the drainage in acres and the number of dry days preceding each storm. A dry day was considered to be one in which less than 0.03 inches/hr or 0.1 inches/day of rainfall were recorded. The washoff loading factor was then calculated on an annual basis and all loading figures averaged over the total study period, to produce a mean annual washoff loading value. Calculations were not done for arsenic since in all cases it was below the detection limit of 0.05 mg/l.

The unit background loading was based on the flow in the system measured prior to the start of a storm and not attributable to the stormwater runoff. In the Central Business District, the background values could not be calculated directly but had to be related to a specific time interval because of the wide fluctuation of concentration values throughout a 24-hour period. These fluctuations were largest for BOD, COD, organic nitrogen, ammonia, phosphate and hexane extractables. A plot of unit loading vs. time was developed from dry weather flow data, particularly that of September 27, and the resulting graphs used to determine background loading for a given time interval (Figures 36 to 38, Appendix 2). The other parameters were found to vary only slightly with time, therefore, only the mean concentration values were used to calculate the background loadings.

TABLE 6

ANALYTICAL METHODS

Dissolved Oxygen - Azide modification of iodometric method, (Standard Methods, 1971).

Biochemical Oxygen Demand - 5 day incubation, (Ibid).

Ammonia - Phenolhypochlorite method, (Zadorny, et al, 1973).

Nitrate - Cadmium reduction method, (Standard Methods, 1971).

Nitrite - Diazotization method, (Ibid).

Kjeldahl Nitrogen - Acid digestion, (Ibid).

Ortho Phosphate - Dissolved ascorbic acid method, (Ibid).

Total Hydrolyzable Phosphorus - Acid hydrolysis followed by ascorbic acid color development, (Ibid).

Hexane Extractable - Soxhlet extraction method, (Ibid).

Suspended Solids - Total suspended matter, (Ibid).

Settleable Solids - Filtration after standing one hour (Ibid).

Total Dissolved Solids - Filtrable residue, (Ibid).

Chloride - Chloride electrode, Orion model 96-17. (Carlson, R.M., and Kennev, D. R., 1971).

Total Coliform - Membrane filter method using M Endo broth. (Standard Methods, 1971).

Fecal Coliform - Membrane filter methods using M F C broth. (Ibid).

Heavy metals except mercury and arsenic - Acidification with nitric acid to 0.4% HNO_3 and determination by atomic absorption, (Ibid).

Mercury - Acid digestion at 95°C for 2 hour and determination by flameless atomic absorption, (EPA, 1971).

Arsenic - Persulfate sulfuric acid digestion to SO_3 fumes followed by generation and atomic absorption analyses in hydrogen-argon flame. (Ibid; Chu et al, 1972).

Temperature - Mercury thermometer. (Standard Methods, 1971).

pH - Determined on a Beckman model 76 expanded scale pH meter, (Ibid).

Conductivity - Hydrolab Surveyor System control unit, (Ibid).

Turbidity - Hach turbidimeter, (Ibid).

Sulfate - Hach turbidimeter, (Ibid).

In later attempting to analyze the data for the Central Business District, it was found that the background information collected was not sufficient to allow for precise calculations, although approximate values were obtained.

RESULTS

The comparison of the seven test areas as to overall quality of runoff based on the mean concentration of pollutants (Tables 7 & 9-15, Appendix 3) produces a general ranking in order of descending quality as follows:

1. Lake Hills
2. Highlands
3. Southcenter
4. Viewridge 1
5. Viewridge 2
6. South Seattle
7. Central Business District

This order was determined by considering all parameters (except temperature, pH and arsenic) with each being given equal weight. The areas were first ranked according to concentration level by parameter. Where equal values occurred, the areas were given equal standings. The overall order was then determined by which position each area fell into most frequently.

The first two sites, which are low density single family residential, yield the highest quality runoff. The Lake Hills area represents the best overall picture, with the lowest or next to lowest concentration levels in 90 percent of the cases. The major exception to this trend is the high coliform levels present in these samples. The total and fecal coliform concentrations of 37,000 and 1400/organisms/100 mls, respectively ranked among the highest values recorded in any of the areas. The total to fecal coliform ratio of 26 to 1 tends to indicate that most of the coliform contamination is from a source other than sanitary sewage. Fecal streptococci concentrations were not run, so further differentiation of the fecal source is not possible.

These coliform concentrations, as well as all other coliform concentrations found in this study, exceed the water quality standards for receiving waters (Dept. of Ecology, 1973).

The runoff from the Highlands area is of high quality although there are a number of constituents which show mid-range values, including heavy metals and solids.

The Southcenter shopping complex, despite the high density automobile traffic has relatively good water quality. This level of quality undoubtedly reflects the result of a well maintained cleaning program for the parking lots at this location. A portion of the parking

TABLE 7

URBAN RUNOFF POLLUTANT CONCENTRATIONS

SUMMARY

Parameter	VR1	VR2	SS3	SC4	LH5	HL6	CBD7**
			Mean Concentration				
Temp. C*	13.1	12.9	14.8	13.3	14.6	10.7	16.6
Cond. umho/cm	125	136	134	99	51	132	210
Turbidity, JTU	30	37	47	18.7	15	22	43
DO, mg/l	8.6	8.9	8.5	9.5	9.6	9.4	7.0
BOD, mg/l	30	30	19	15	8.5	8.0	22
COD, mg/l	95	97	95	70	68	57	66
Hexane Ext., mg/l	12	16	14	11	7.3	8.5	6.8
Chloride, mg/l	7.7	12	12.2	6.6	5.3	7.5	24
Sulfate, mg/l	17	18	26.1	18	7	18	25
Organic N, mg/l	2.6	3.5	1.7	1.4	1.4	1.4	1.1
Ammonia N, mg/l	0.32	0.48	0.32	0.32	0.19	0.09	0.88
Nitrite N, mg/l	0.11	0.12	0.06	0.04	0.03	0.02	0.12
Nitrate N, mg/l	0.67	0.72	0.83	0.64	0.51	0.76	0.72
Hydrolyzable P, mg/l	0.45	0.40	0.24	0.17	0.24	0.35	0.71
Ortho P, mg/l	0.12	0.12	0.08	0.05	0.12	0.10	0.16
Copper, mg/l	0.040	0.056	0.10	0.081	0.076	0.12	0.44
Lead, mg/l	0.44	0.32	0.25	0.40	0.27	0.08	0.37
Iron, mg/l	2.4	2.0	2.1	0.75	0.39	0.44	2.0
Mercury, mg/l	0.0003	0.0004	0.0004	0.0008	0.0003	0.0008	0.0005
Chromium, mg/l	0.025	0.009	0.010	0.074	0.010	0.010	0.28
Cadmium, mg/l	0.005	0.004	0.005	0.004	0.004	0.004	0.013
Zinc, mg/l	0.18	0.12	0.43	0.24	0.082	0.068	0.86
Sett. Solids, mg/l	51	84	60	40	40	68	113
Susp. Solids, mg/l	85	112	80	73	54	98	190
TDS, mg/l	134	125	170	89	72	101	208
Total Coliform* org./100 mls	28000	26000	4200	1600	37000	1600	4600000
Fecal Coliform* org/100 mls	3600	1200	30	370	1400	370	440000

*Median

** Due to limited background data from this area, these values are approximate

lot is cleaned by vacuum on a weekly basis which appears to be an efficient operation. The constituents of highest quality include conductivity, turbidity and dissolved oxygen levels. Coliform levels are low and very little discharge of nutrients exist. Surprisingly, oil and grease, which were expected to be present in a high concentration, are lower here than at several other stations including Viewridge One. The major heavy metal contaminants from the Southcenter site are lead, chromium and zinc. The lead and zinc contaminants can be related to automobile emissions, while the chromium was traced to a cooling water discharge from the shopping center. Steps are being taken to eliminate the chromium source from the stormwater system.

The two Viewridge areas are nearly comparable in quality of runoff for most pollutants despite the difference in land use. A major contributor to this similarity and to the high concentration levels of constituents in the Viewridge One runoff could be the result of the unseparated roof drains. The major drainage from this site as a result occurs from the residential streets which have been demonstrated to be highly contaminated sources of pollutants (Sartor & Boyd, Nov., 1972). The 50 percent composition of single family residences in the Viewridge Two area likewise adds to the similarity.

Differences in runoff quality between the two areas are seen mainly in the concentration levels for heavy metals, where the values for Viewridge One exceed those for Viewridge Two in most cases; and settled and suspended solids, where Viewridge Two yields the greater values. The reason for the latter difference is not readily apparent. A major arterial does traverse the lower basin (VR2) which could influence the solids loading. This factor correlates with the higher accumulation of oil and grease in the latter area, but the same is not true of other general indicators of vehicular traffic such as lead content.

The South Seattle area is quite similar to the Viewridge areas in the overall quality of runoff. The concentration level for TDS and the turbidity are quite high. However, the values for the heavy metals, which might be expected to be high, are mainly mid-range, with the exception of zinc.

In the Central Business District, the concentration levels of many contaminants are the highest recorded in the study. This indicates a condition of gross contamination. The data collected at this site, however, must be interpreted with caution since inaccuracies could very well exist. The data derived from the combined sewer system by difference can be affected by several factors. The first is the high background concentration levels of the raw sewage which, in general, exceed the stormwater levels by at least one order of magnitude. The second is the wide fluctuation in concentration levels with time wherein the change in concentration levels exceed the stormwater concentrations by a large factor also. The development of good representative background data in this situation is very difficult.

Another problem associated with sampling at this site was the intermittent discharge of industrial wastes. Heavy metals concentration, in particular, were apparently strongly influenced by the effluent discharge from a single plating shop. The wide fluctuation noted in metal concentrations between storms substantiates this observation. The limited background data from this area made it impossible to calculate these values as precisely as those from the other areas. While these values are therefore considered approximate, they do reflect the general trend.

The washoff loading intensities (pounds/acre/year) show a good relationship to percentage of runoff as well as to quality of runoff. The washoff loading intensities calculated for the overall study period and for each individual storm are presented in Table 8 & 16 to 22, Appendix 4. The ranking of the calibration sites based on relative washoff loading intensities was determined by the same method as outlined previously and is presented below in order of ascending quantity.

1. Highlands
2. Lake Hills
3. Viewridge One
4. South Seattle
5. Southcenter
6. Viewridge Two
7. Central Business District

This order of ranking is similar to that illustrated for quality of runoff based on mean concentration although some change in emphasis has occurred. The Highlands area is the best in terms of mean annual washoff loading although the Lake Hills area ranks very high. The Viewridge One, South Seattle, and Southcenter areas yield similar values. The washoff loading intensity for the Viewridge Two area is significantly greater, although it is still exceeded by that for the Central Business District.

The low washoff loading intensities at the Highlands and Lake Hills sites are directly related to both the quality and quantity of runoff. As noted previously, the quality of runoff from these two sites was the best and the percentages of runoff were extremely low, 4.9 and 7.4 percent respectively. The differences in level between the loading intensities recorded at these sites and that at the Central Business District approaches at least one order of magnitude. This holds particularly for biochemical oxygen demands, ammonia, iron and chromium.

The mean washoff loading figures from Viewridge One, South Seattle and Southcenter are of the same general magnitude. This relationship exists despite the wide variation in percentage of runoff from these three sites: Namely: 13.6, 34.9 and 53.9 percent. The loading from the Viewridge One area could be higher than anticipated because of the loss of runoff due to the unseparated roof drains. The magnitude of

TABLE 8

URBAN RUNOFF POLLUTION LOADING

SUMMARY

Parameter	VR1	VR2	SS3	SC4	LH5	HL6	CBD7**
	Mean Loading, pounds/acre/year*						
BOD	7.1	92	7.1	14	3.6	0.58	110
COD	54	340	39	68	33	12	325
Hexane Ext.	17	144	8.4	13	4.4	2.0	47
Chloride	1.8	20	3.0	3.7	2.3	2.1	113
Sulfate	3.6	44	14	11	3.0	5.8	32
Organic N	0.8	1.5	1.0	1.5	0.47	0.27	8.0
Ammonia N	0.14	0.14	0.19	0.26	0.071	0.02	6.2
Nitrite N	0.019	0.32	0.030	0.032	0.009	0.004	0.44
Nitrate N	0.22	3.1	0.44	0.58	0.22	0.28	3.6
Hydrolyzable P	0.25	1.8	0.16	0.17	0.096	0.071	5.5
Ortho P	0.048	0.20	0.040	0.052	0.034	0.017	1.2
Copper	0.037	0.23	0.085	0.09	0.026	0.028	1.9
Lead	0.15	0.67	0.14	0.34	0.12	0.028	1.9
Iron	0.75	3.6	0.68	0.55	0.17	0.08	8.0
Chromium	0.009	0.04	0.009	0.062	0.005	0.003	1.6
Cadmium	0.004	0.019	0.004	0.004	0.002	0.002	0.079
Zinc	0.05	0.22	0.21	0.21	0.029	0.015	2.9
Sett. Solids	42.7	240	40	49	21	9.2	511
Susp. Solids	107	760	56	87	29	21	964
TDS	36	610	153	52	35	22	1410

*February 1973 to September 1973.

**Due to limited background data from this area, these values are approximate

individual parameters within these three areas do differ significantly in many cases, but without any apparent general trend. For example, solids discharge is highest from the Viewridge One area, oxygen demand is highest from Southcenter, while nutrients vary. Nitrogen discharge is highest from the latter site while phosphorus loading is highest from the Viewridge One area. Overall, Southcenter appears to produce the higher loadings although all three are quite similar in magnitude.

Despite the similarity in quality of runoff between the two Viewridge sample sites, their washoff loading intensities differ substantially. The percentage of stormwater runoff from the two sites differs substantially with that at the latter site being three times the former i.e., 13.6 vs. 33.8 percent. The parameters of major significance discharged from the Viewridge Two site are solids, BOD, COD and oil. The nutrient content is also relatively high in comparison to the upstream site, but these levels are not of major importance to the receiving waters.

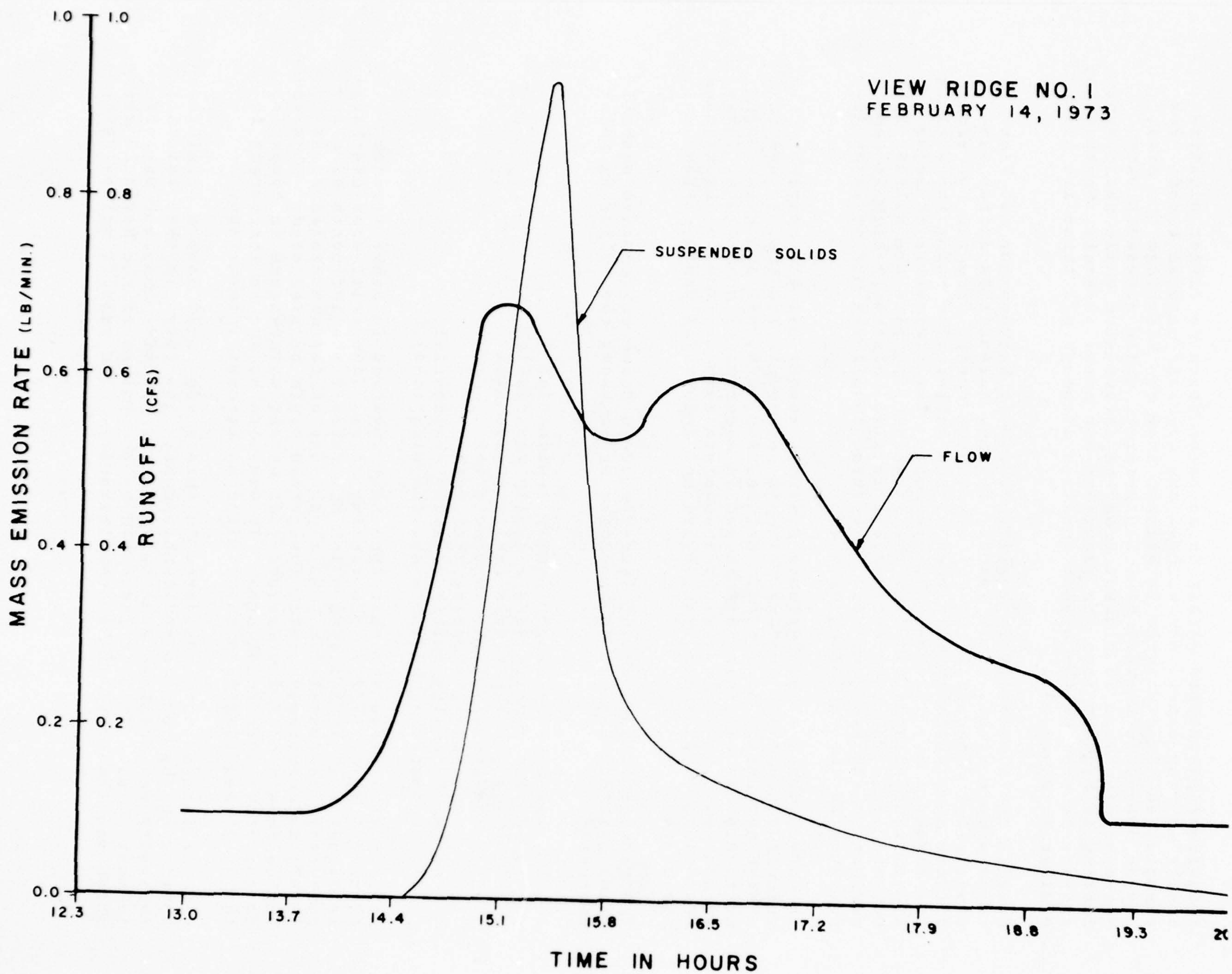
As noted, the Central Business District runoff has the heaviest washoff contaminant loading which is related to low quality and to a high percentage of runoff. Solids, BOD, COD, oil and grease and nutrients are all being discharged in substantial quantities. These values could be influenced by incomplete compensation for background contamination including raw sewage and industrial waste streams in the systems.

The ranking of the various land-use areas based on relative washoff loading intensities in an ascending order shows the following relationship:

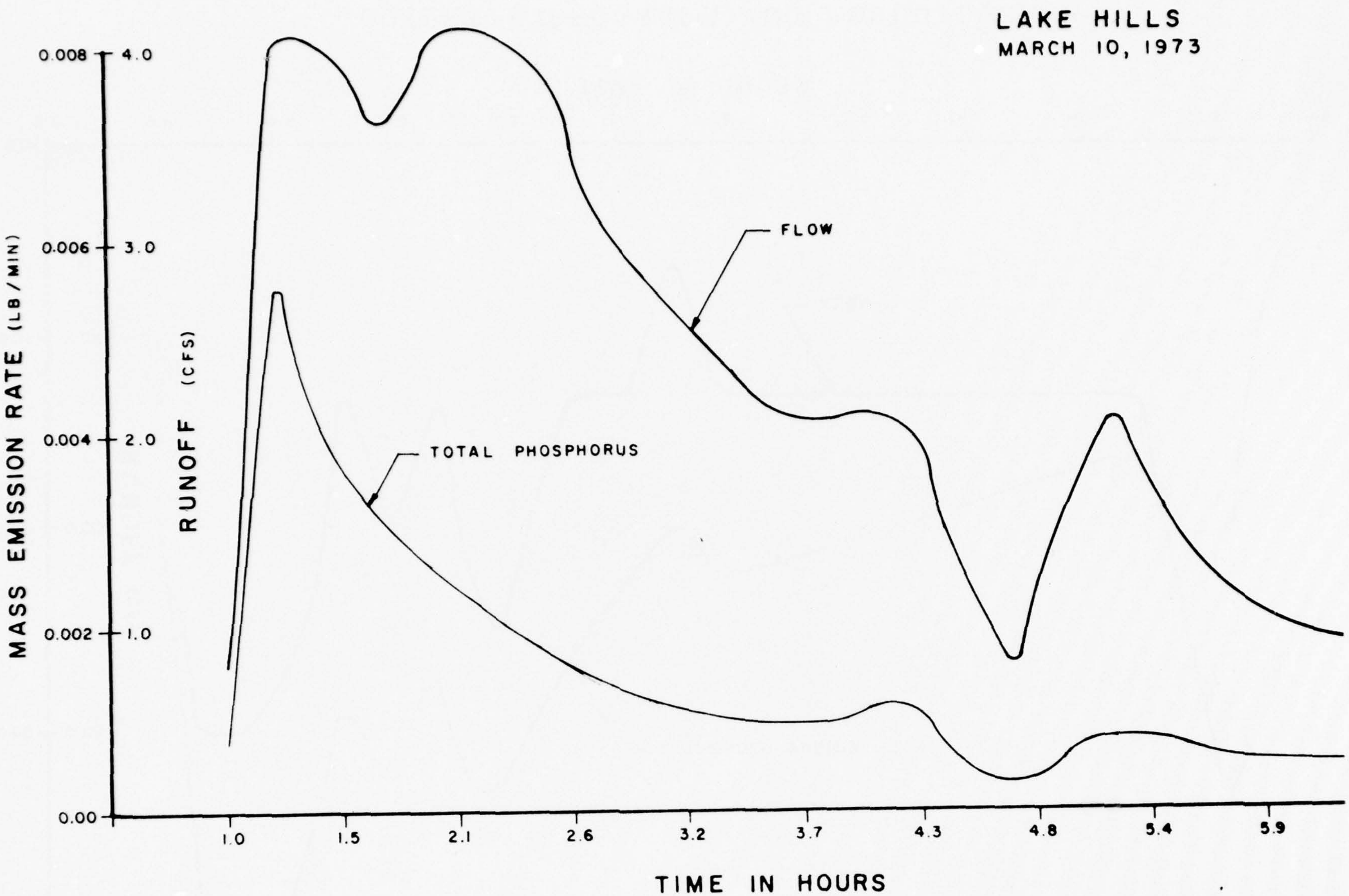
1. Low density single family residential
2. Medium density single family residential
3. High density single family residential
4. Industrial, light manufacturing
5. Commercial, shopping area (new)
6. High density multiple family residential
7. Commercial, business and shopping (old)

This order differs somewhat from that observed in other studies (Sartor & Boyd, 1972). The ranking of the industrial area discharge is higher than anticipated which may reflect the influence of a low percentage of runoff for this area. One of the commercial areas (CBD7) is conversely ranked lower than would be predicted. This could be the result of a low frequency of street maintenance in comparison to the other commercial area. It may also be due to inaccuracy in the data resulting from the limited background information.

Several factors not considered in this study could have a significant bearing on the results and conclusions. The first is that rainfall intensity may not have been sufficient to provide complete washoff in most cases. This is indicated by the values of the March 10 storm, which was the storm of highest intensity. The washoff values recorded

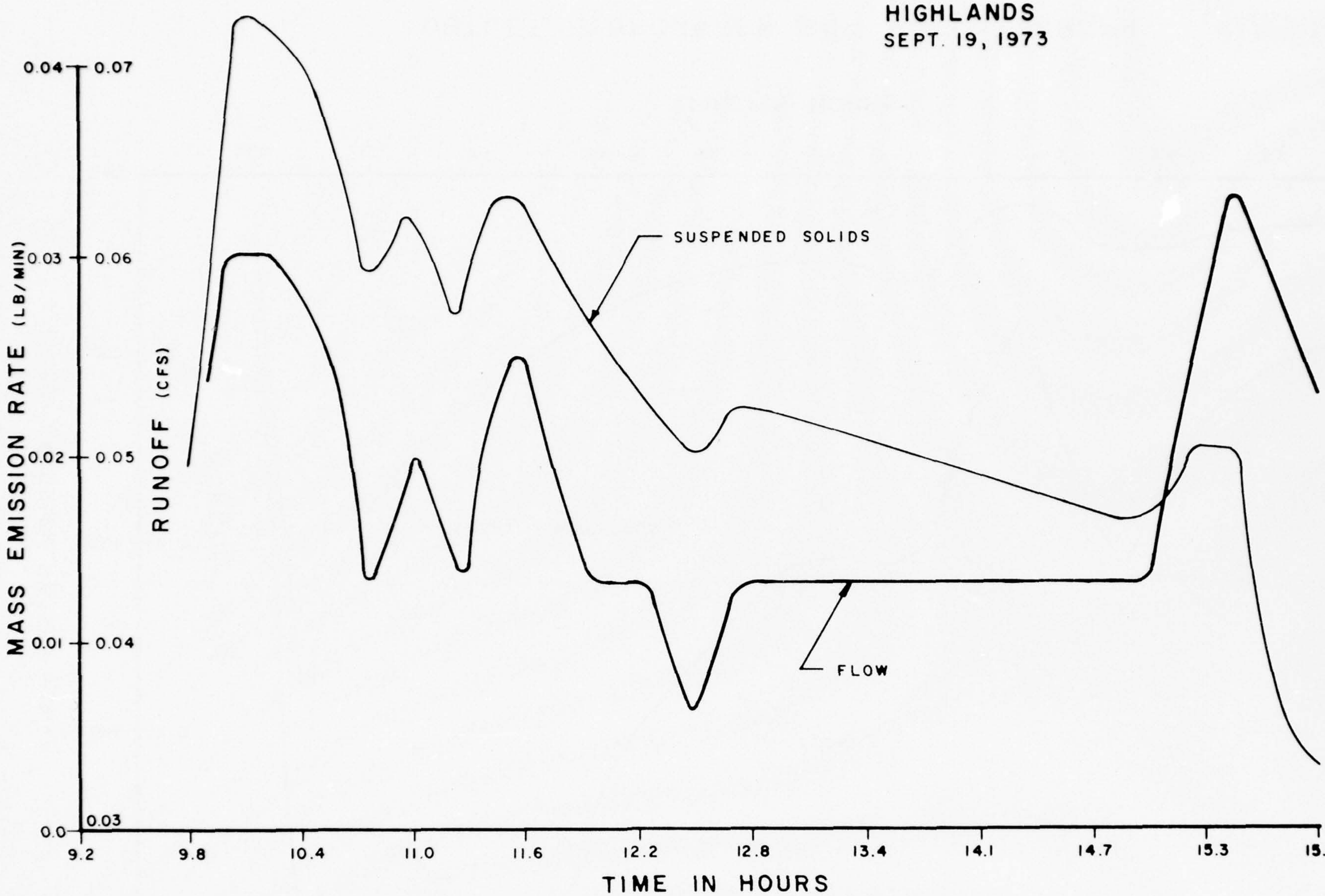


VIEW RIDGE NO. 1
FEBRUARY 14, 1973
SUSPENDED SOLIDS
FLOW
MASS EMISSION RATE (LB/MIN.)
RUNOFF (CFS)
0.0
0.2
0.4
0.6
0.8
1.0
12.3
13.0
13.7
14.4
15.1
15.8
16.5
17.2
17.9
18.8
19.3
TIME IN HOURS



OUTLET HYDROGRAPH AND POLLUTOGRAPH

FIGURE 23



OUTLET HYDROGRAPH AND POLLUTOGRAPH

on this date exceed the mean loadings in over 90 percent of the cases, indicating a below average washoff for some of the less intense storms. A more complete cross-section of storm intensities needs to be sampled before a good relationship between washoff loading and rainfall intensity can be established. Likewise, the storms sampled for quality are all relatively low volume storms in terms of total rainfall volumes. At least one large volume storm needs to be sampled to establish a good overall relationship between washoff loading and total volume. The study period did not cover an entire year, so no indications of seasonal variation are available. Records of sweeping schedules are poorly maintained which essentially eliminates consideration of this factor in calculating the period of contaminant accumulation. This information needs to be developed more completely to provide precise information on periods of accumulation and on the effectiveness of the cleaning procedures employed.

A preliminary analysis of pollutant loading vs. time for BOD, total hydrolyzable phosphorus and suspended solids was carried out. Graphs of the data reveal that in almost all cases washoff loading is decreasing relative to the runoff flow. A rapid removal of most of the pollutant early in the storm followed by a low sustained level of washoff, the first flush effect, was the pattern observed in 17 percent of the cases (Figure 22). In another 21 percent of the cases the pattern was similar but not as clear cut, i.e.,an extended first flush (Figure 23). The largest number of cases revealed a loading pattern that corresponded to the runoff flow but was decreasing relative to it (Figure 24).

The loading patterns varied between parameters for a given location and storm, between locations and between storms. There are a number of factors influencing this variation including runoff flow pattern and volume; rainfall intensity, volume and duration; area, and the kind and amount of pollutant. Although thorough understanding of the relationships involved would require a more extensive study, some of the correlations are apparent in the data.

The pollutant loading pattern coincides most closely with the runoff flow pattern. A sudden initial peak in flow followed by a fluctuating period or a gradual decline is most often associated with the first flush loading patterns. A runoff flow pattern of separated peaks corresponds to the fluctuating but declining loading pattern.

The loading pattern is also related to storm intensity with the first flush effect occurring most often for high intensity storms.

SUMMARY

A survey to measure the quantity and quality of urban stormwater runoff in the metropolitan area of Seattle, Washington was initiated to provide data for calibrating the RIBCO Urban Runoff and Basin Drainage Computer Simulation Model. Seven calibration areas were selected based on land use patterns as follows: single family residential, multiple family residential, commercial and industrial. The study was conducted over a seven-month period, February to September, 1973 and included measurement of rainfall volume and intensity, and stormwater runoff volume, intensity, and quality.

The quantity data, including rainfall and runoff, was collected on a continuous basis at all calibration sites. The rainfall during the period was unusually light averaging 1.39 in/month which represents an average deviation of 0.8 inches below the normal rainfall for this area. The light rainfall contributed to below average runoff for the various land use areas. The percentages of runoff are as follows: single family residential - 5 to 14%, multiple family residential - 34%, industrial - 35%, and commercial - 54 to 64%.

The runoff quality measurements were conducted over a total of six storms which ranged in volume from light (less than 0.1 in.) to moderate (0.5 in.). Technical difficulties prevented sampling of the heavier storms providing an incomplete range of values for determination of the washoff loading function. The pollutants highest in concentration were suspended and settleable solids, BOD, COD and oil. Nutrients concentrations, in general, were low while heavy metal values varied with influence from industrial waste discharge and/or vehicular traffic volumes.

The washoff loading factors for the various pollutants correlated closely with land use pattern within the calibration sites. The ranking, based on mean annual washoff loading, of the designated land uses according to increasing pollution potential produced the following order: low density residential, high density residential, new commercial, industrial, multiple residential, old commercial. This ranking deviates somewhat from that recorded in other areas of the country particularly in regard to the industrial area and the old commercial area. This may be related to the low percentage of runoff for the industrial area and the limited background data from the old commercial area.

The factors not sufficiently accounted for in this study, including a representative range of rainfall volume and intensity, season, background loading and street maintenance, may have some affect on the results. Further data collection is recommended in order to provide the necessary data base to substantiate the results and conclusions drawn from this study.

CONCLUSIONS

1. The variation of rainfall with geographic location during individual storms creates a problem in precise determination of rainfall volume and intensity particularly for large-area survey sites.

2. The percentages of runoff, ranging from 5 to 64 percent, correlated well with the percentage of impervious surface associated with a particular land use.

3. An incomplete range of storms was sampled both in relationship to season and total volume and intensity. This may produce inaccuracies in the simulation of the total spectrum of storms.

4. The light rainfall may have provided incomplete washoff of accumulated pollutants as well as low percentages of runoff. The potential contribution in subsequent storms would produce some variability in results.

5. Five major constituents found in the urban runoff were solids, BOD, COD, oil and grease and total coliforms.

6. Heavy metal concentrations in some areas were not typical of urban runoff and represented input from other sources.

7. The concentration levels of contaminants in the Central Business District samples generally exceeded those for all other areas. This may reflect incomplete compensation for background levels of contaminants in the combined sewer system.

8. The washoff loading factors were related to the number of dry days preceeding a given storm with no consideration of street maintenance schedules. This could contribute to low values if any maintenance was performed during the designated accumulation period.

9. The washoff pollutant loading factors calculated for the Seattle area are, in general, less than those listed for many other cities in this country. This is particularly true in comparison to street surface contaminants, including solids, oil, nutrients and heavy metals.

10. Washoff pollutant loading factors are closely correlated with land use pattern. The ranking of land use categories according to pollution potential corresponds to a normal pattern with the exception of the industrial site which is better than anticipated, and the old commercial site which is worse.

11. The low washoff loading factor for the industrial site can be attributed, in part at least, to unpaved areas and possible ponding on the flat surface. This is indicated by a low percentage of runoff, i.e., 35%.

12. Washoff pollutant loading (for BOD, total phosphorus and suspended solids) was found to be decreasing relative to flow during the course of the storm in almost all cases. The first flush effect was observed in about one-third of cases.

RECOMMENDATIONS

1. The present urban stormwater sampling program should be extended over a longer period of time to include at least a full annual cycle of rainfall. This would provide the necessary seasonal data for model calibration and for correlation analysis.

2. A more complete rain gauge network should be established to provide a more precise definition of rainfall volume and intensity particularly in large survey areas.

3. Storms of greater volume and intensity need to be sampled. This would produce a more complete washoff of pollutants and provide the necessary statistical data base for the model calibration.

4. The pollutant buildup on streets should be studied and a correlation between antecedent dry days and pollutant loading established. Concurrently more complete records of street maintenance programs should be obtained and the type and frequency of maintenance correlated with a reduction in loading levels. This would eliminate errors in the calculation of washoff loading factors based on antecedent dry days where pollutant accumulation has been affected by street cleaning.

5. An alternate means of gauging stormwater runoff flow should be developed to allow calibration of present methods.

6. Automatic sampling equipment should be utilized in subsequent studies. This will insure better sampling coverage and lower manpower requirements.

7. A more complete analysis of the data is desireable whenever sufficient data has been accumulated for this purpose. Such factors as correlation of stormwater quality and washoff pollutant loading with rainfall volume and intensity, with time during the storm, with season, with period of accumulation, with maintenance practices, etc., should be considered. The definition of washoff loading in relationship to the solid and liquid portions of the runoff also needs to be determined.

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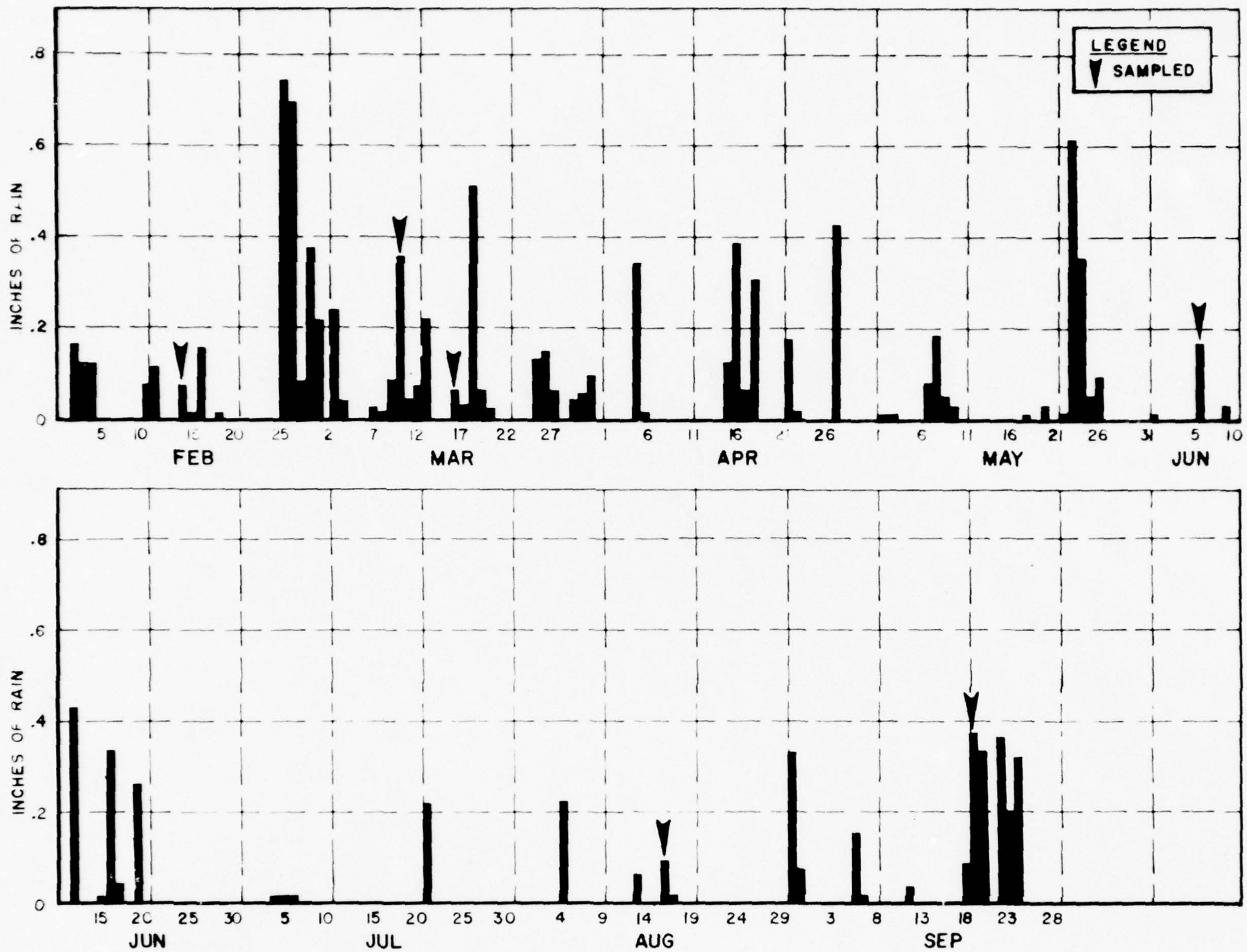
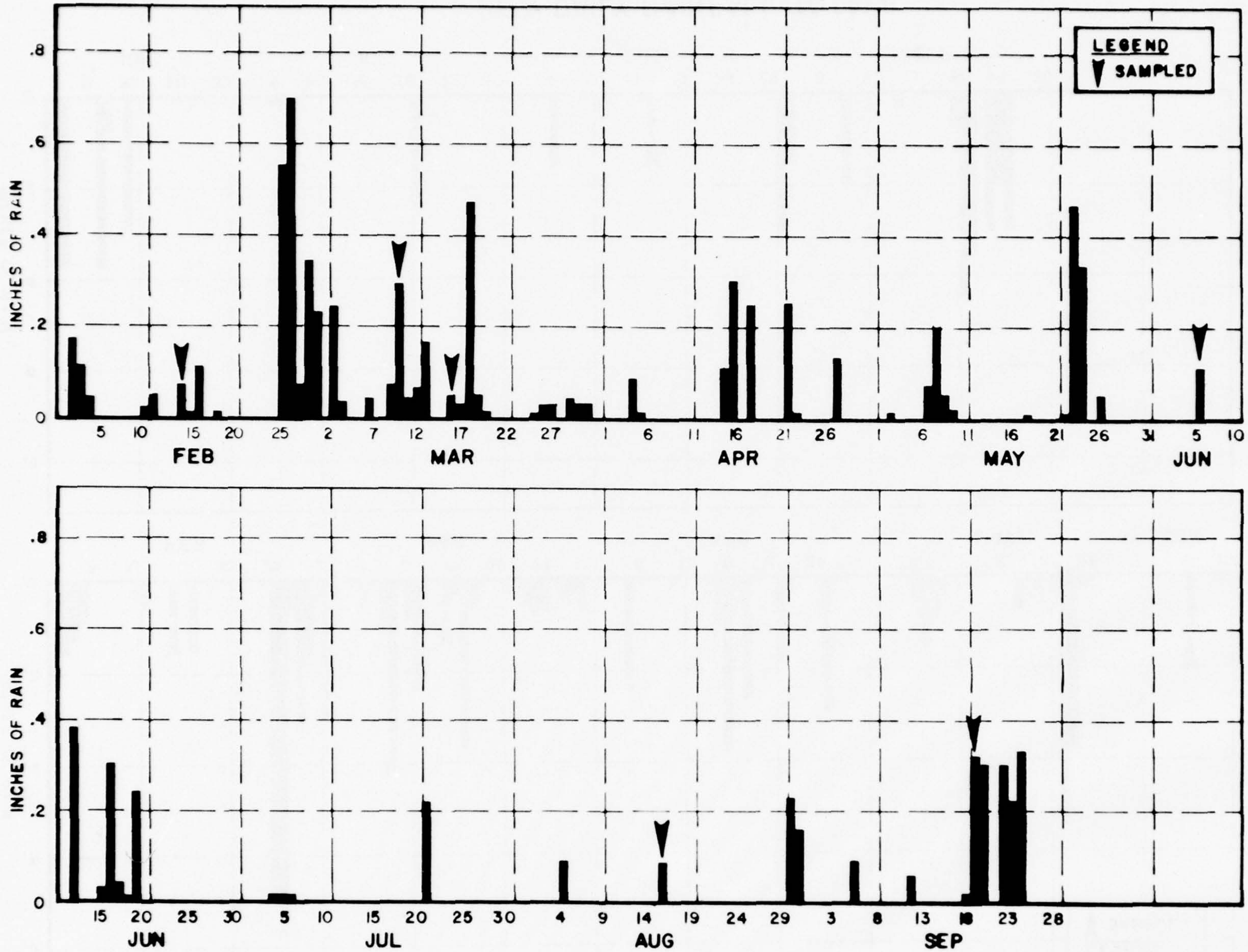
APPENDIX A

DAILY RAINFALL TOTALS



1973 DAILY RAINFALL TOTALS

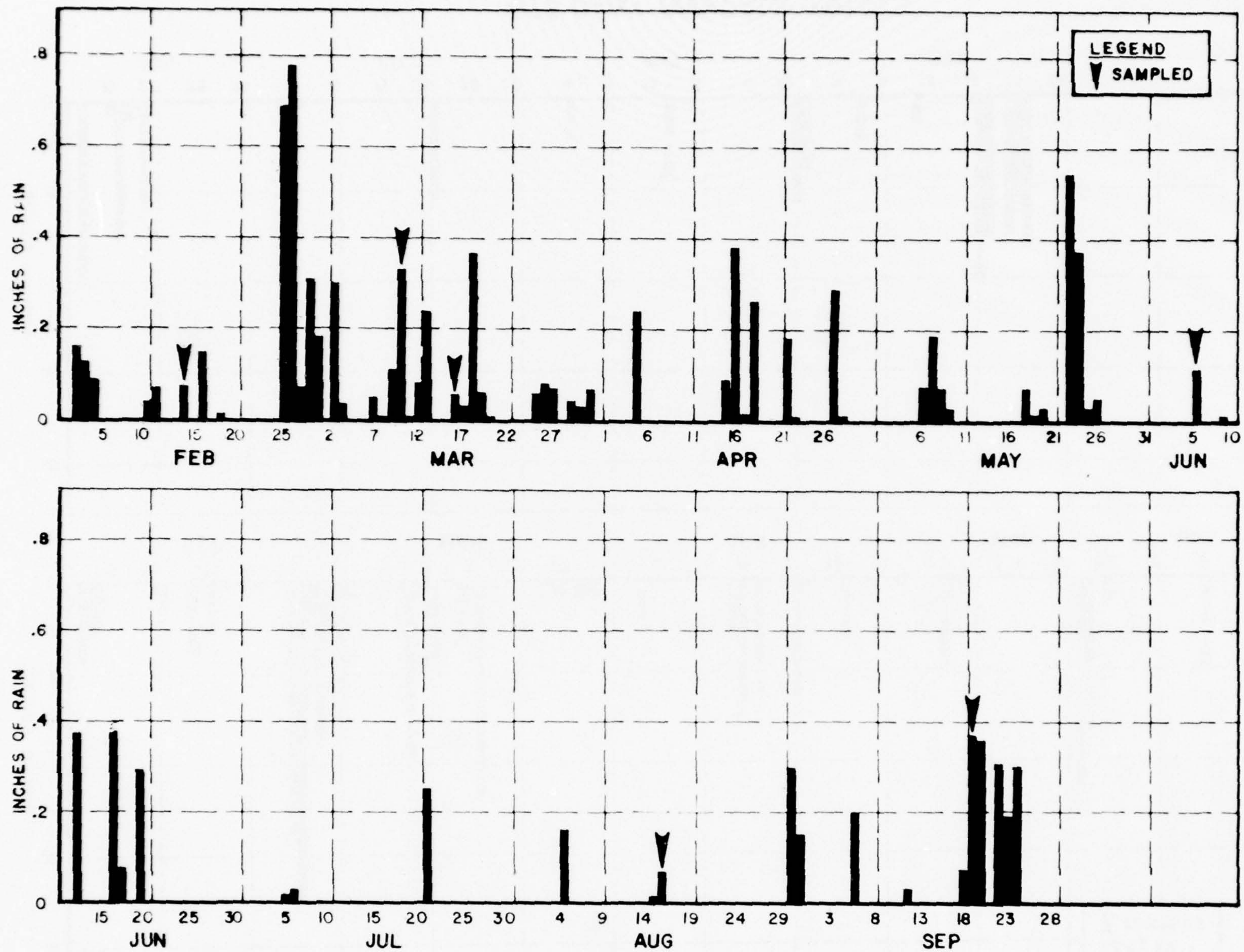
MATTHEWS BEACH PUMP STATION



1973 DAILY RAINFALL TOTALS

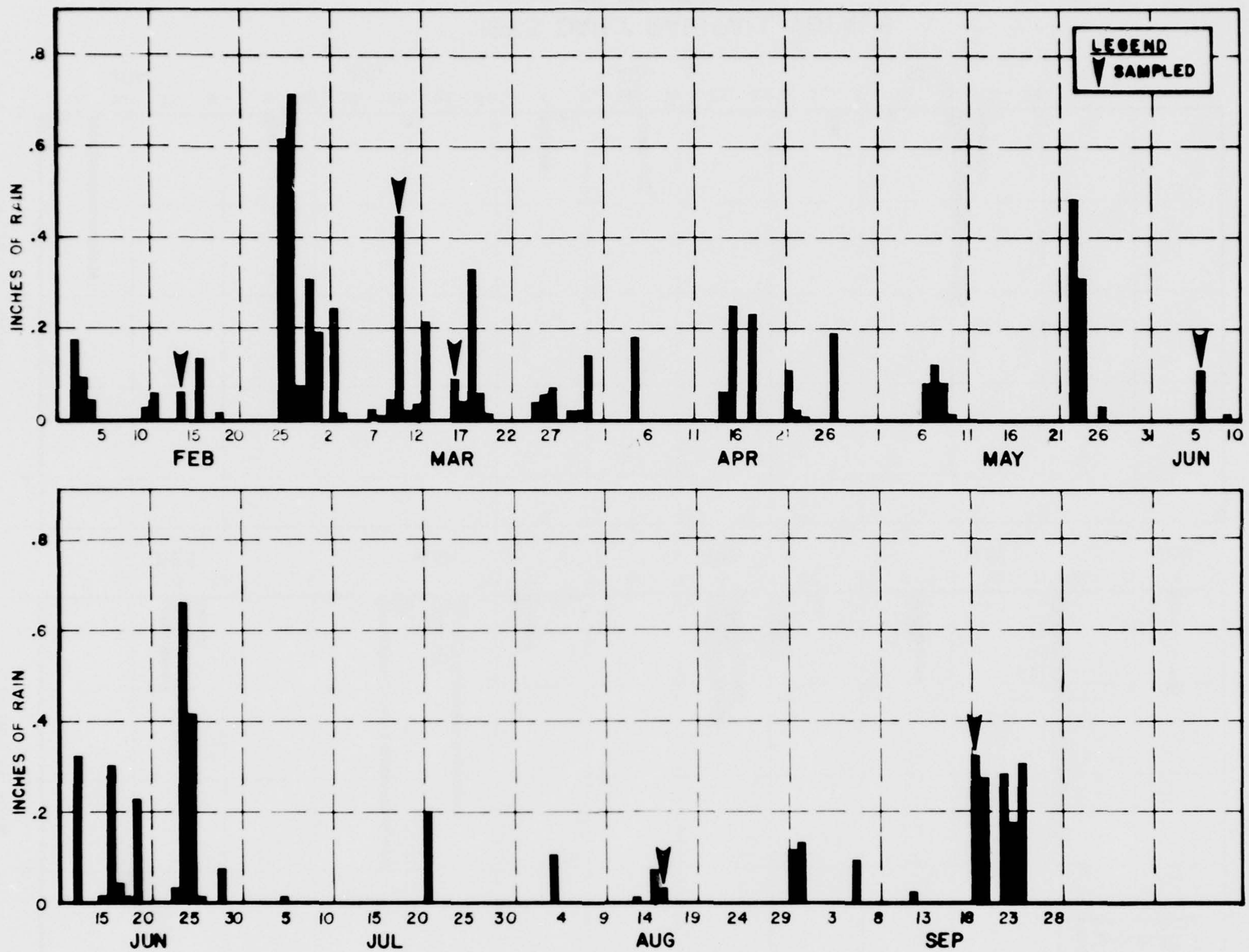
UNIVERSITY OF WASHINGTON

FIGURE 26



1973 DAILY RAINFALL TOTALS

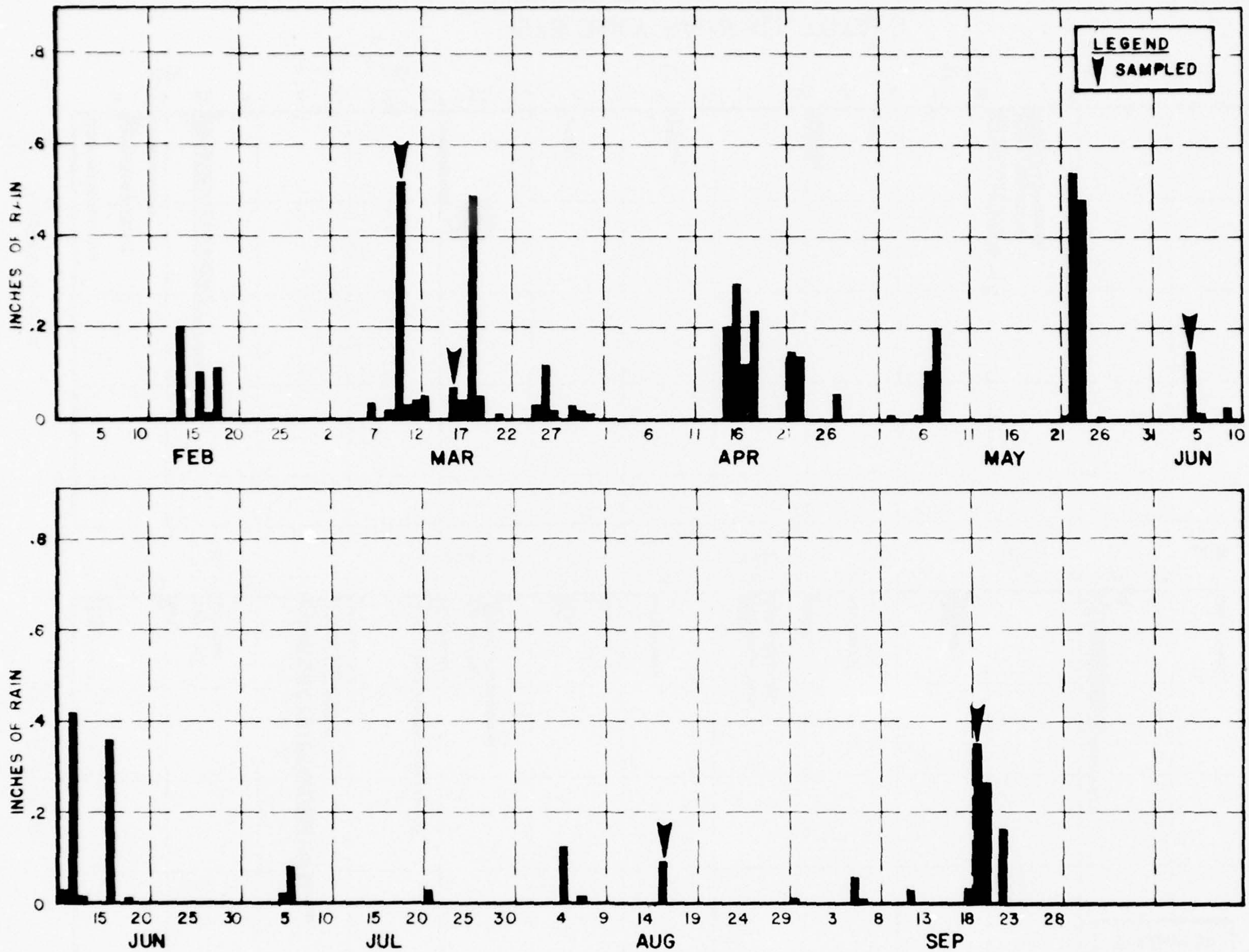
MAPLE LEAF RESERVOIR



1973 DAILY RAINFALL TOTALS

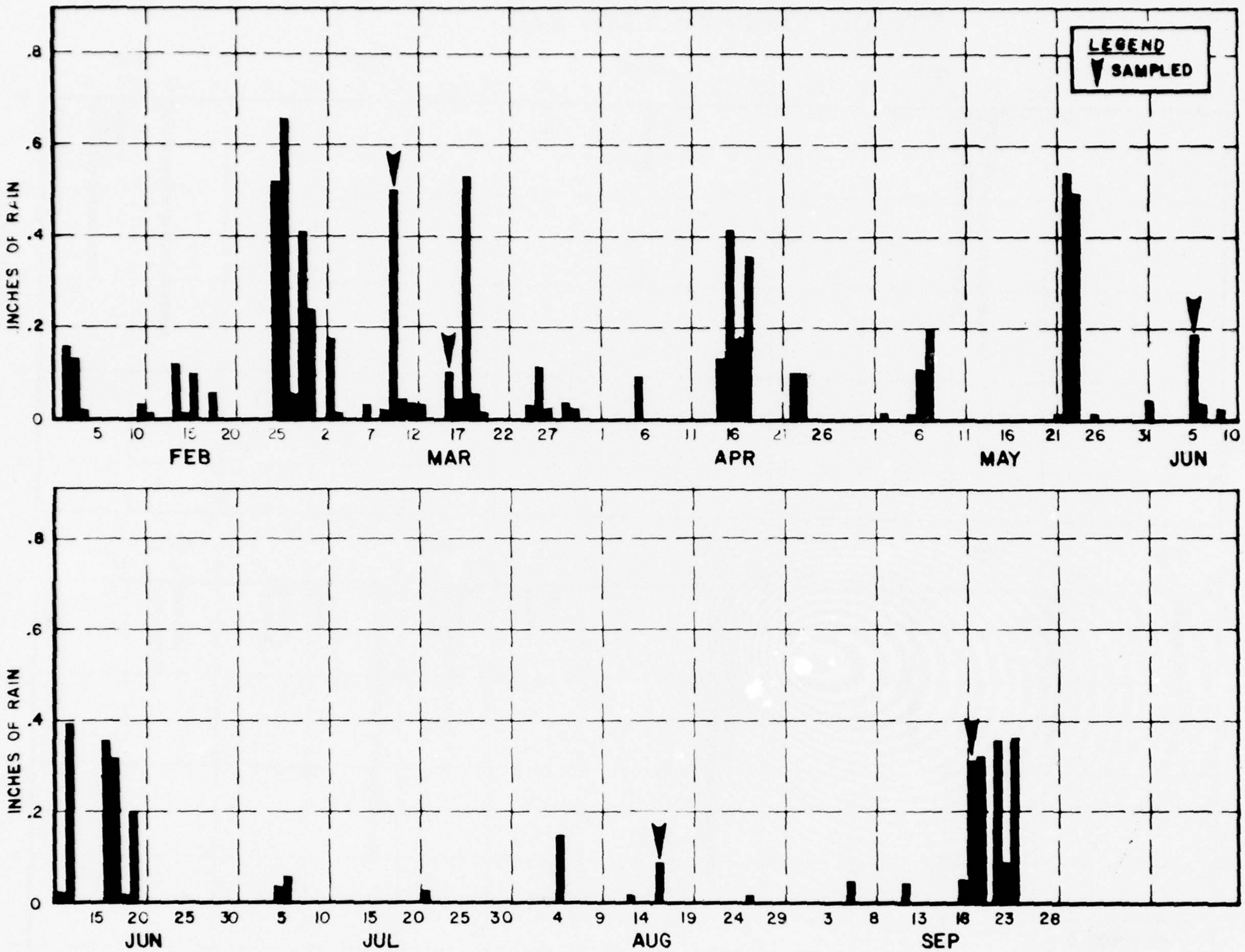
VIEWRIDGE TWO

FIGURE 28



1973 DAILY RAINFALL TOTALS

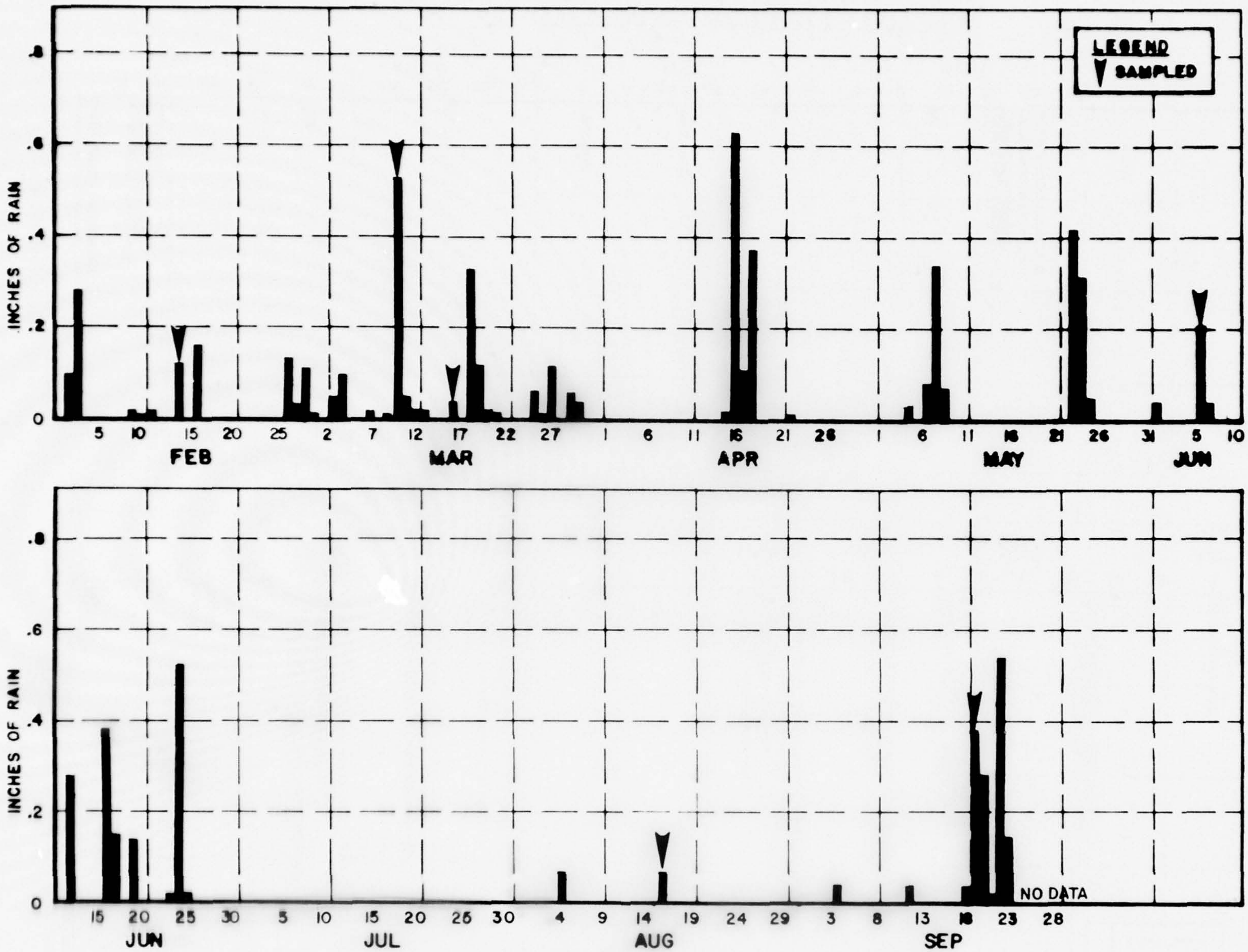
DIAGONAL AVE. TREATMENT PLANT



1973 DAILY RAINFALL TOTALS

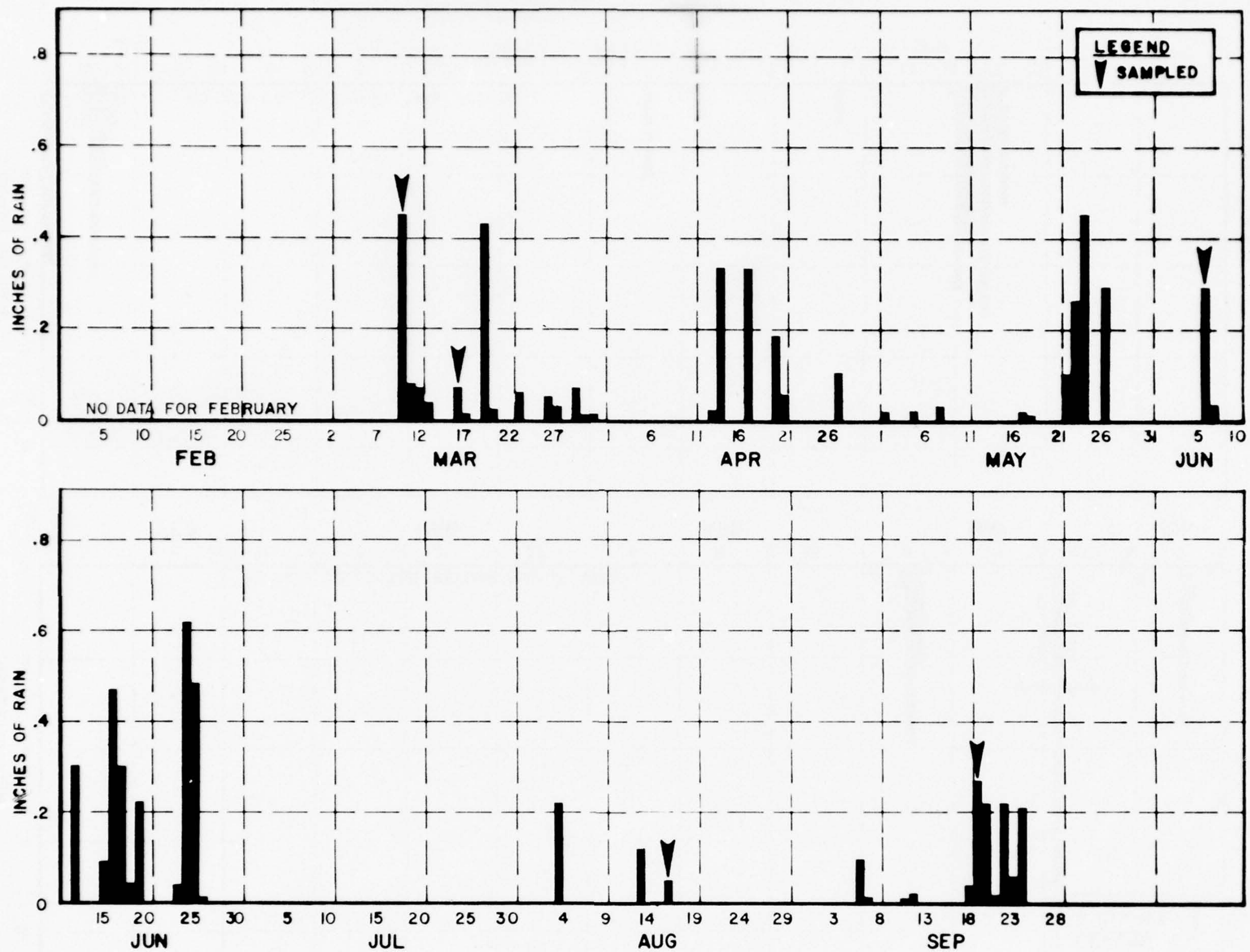
E. MARGINAL WAY PUMP STATION

FIGURE 30



1973 DAILY RAINFALL TOTALS

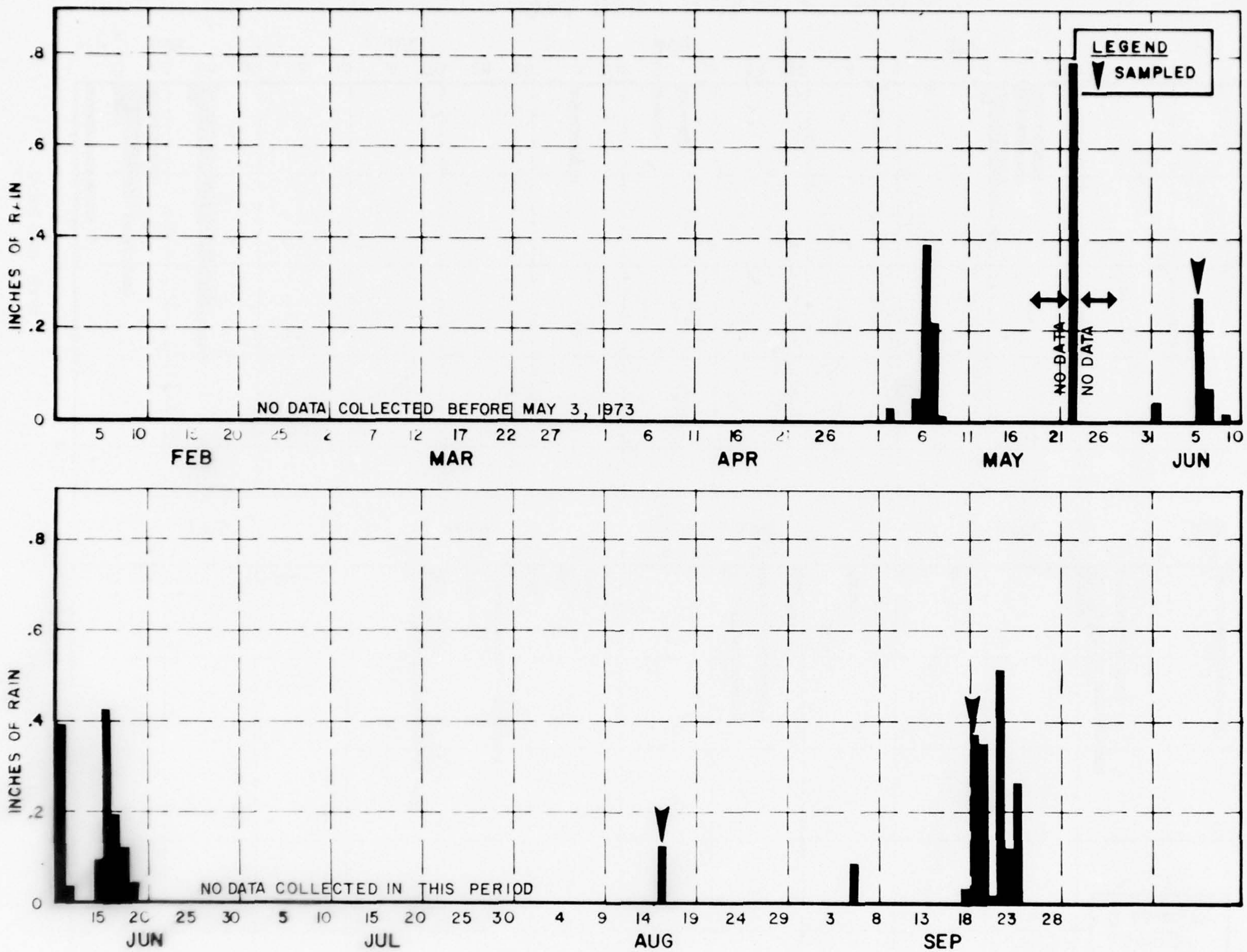
RENTON TREATMENT PLANT



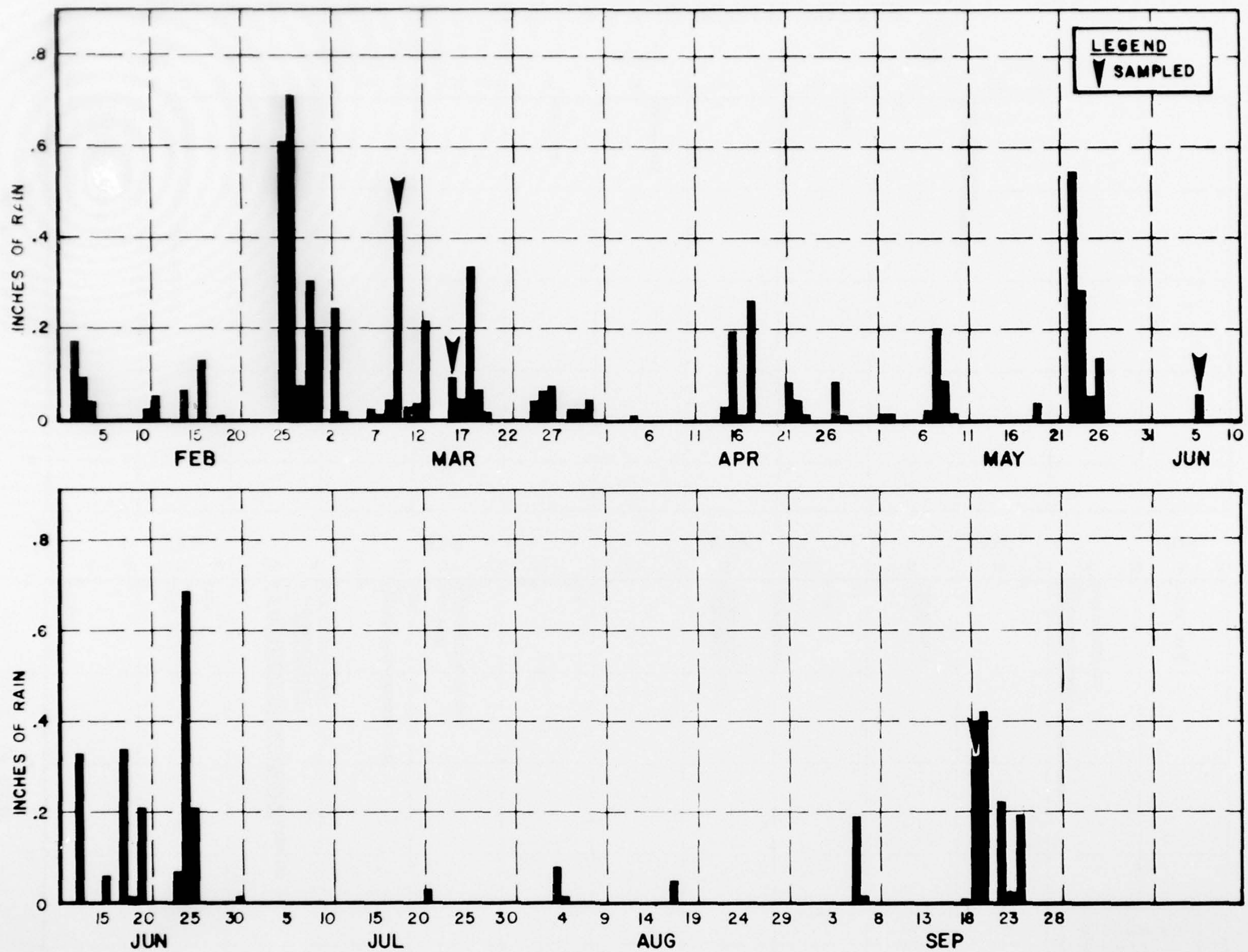
1973 DAILY RAINFALL TOTALS

LAKE HILLS FIVE

FIGURE 32



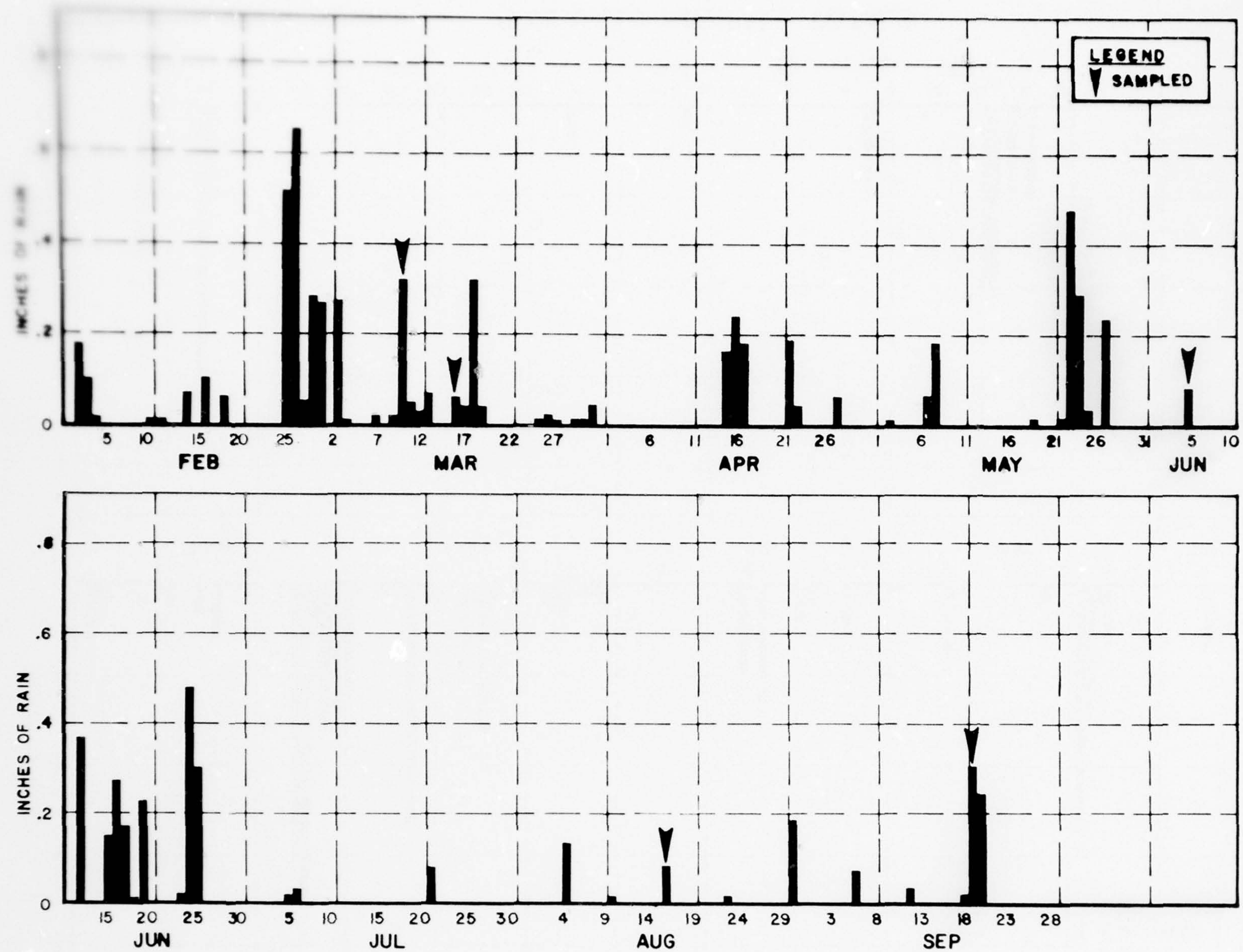
1973 DAILY RAINFALL TOTALS



1973 DAILY RAINFALL TOTALS

HIDDEN LAKE PUMP STATION

FIGURE 34



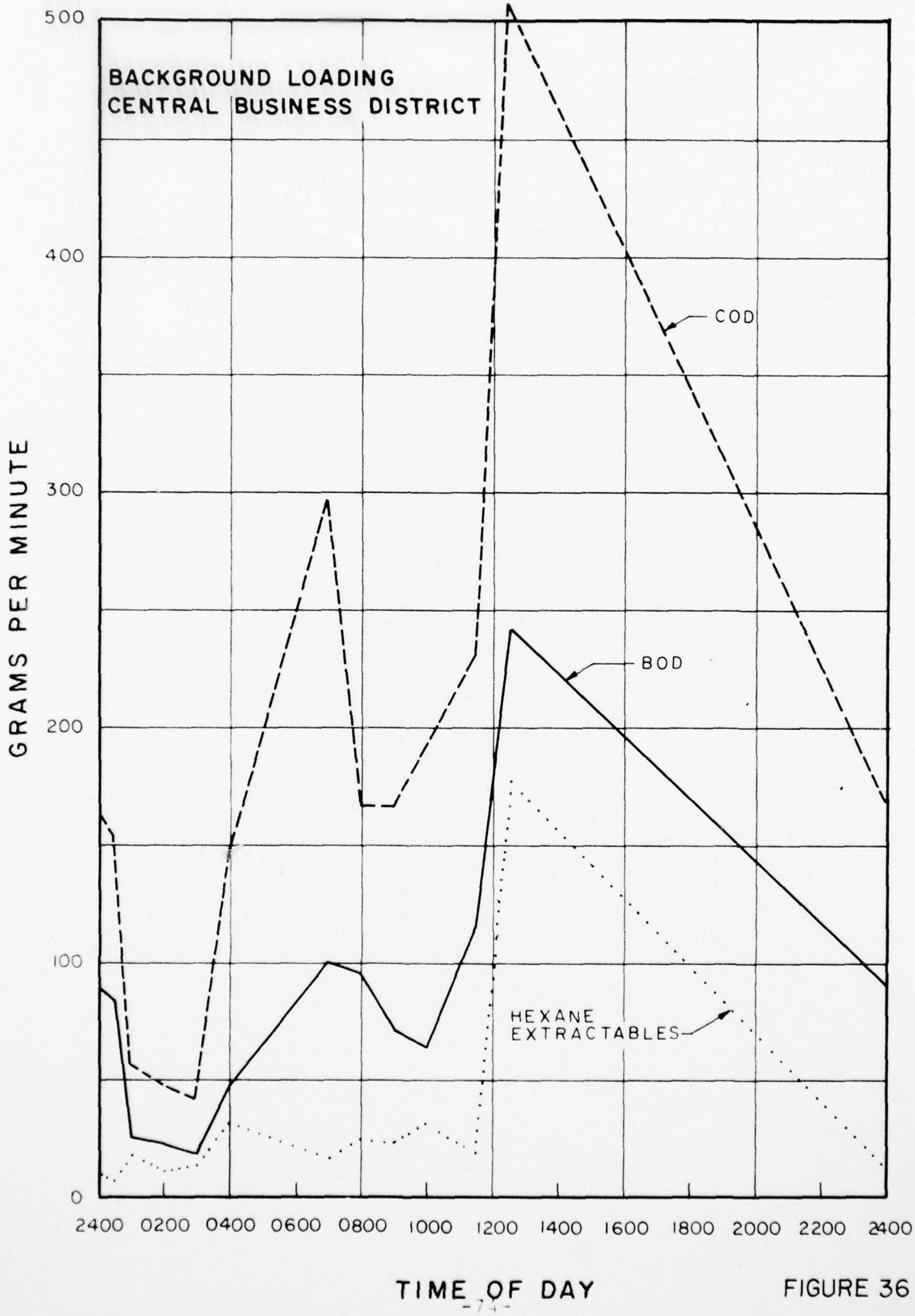
1973 DAILY RAINFALL TOTALS

DENNY WAY PUMP STATION

APPENDIX B

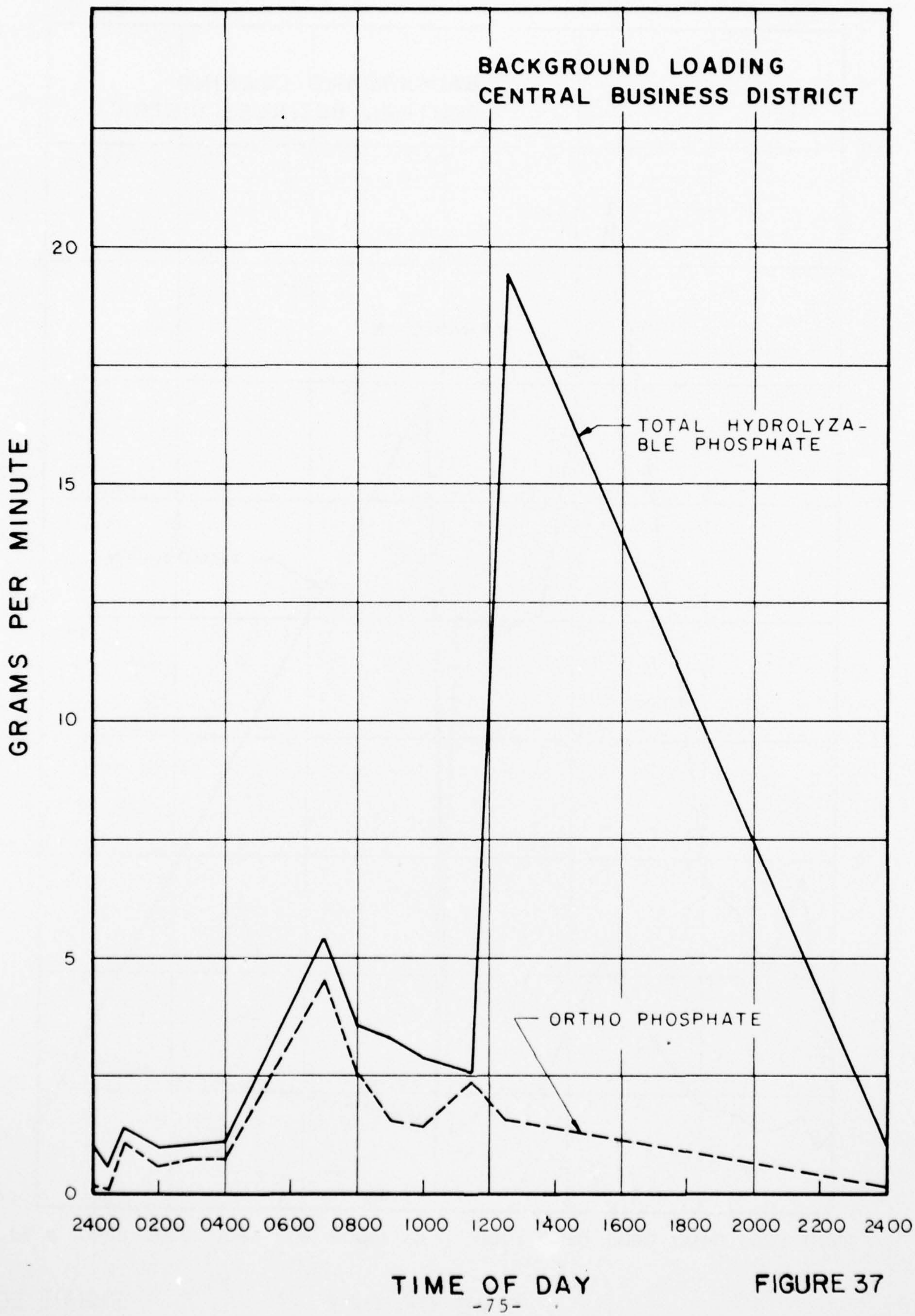
BACKGROUND LOADING

CENTRAL BUSINESS DISTRICT



BACKGROUND LOADING
CENTRAL BUSINESS DISTRICT
COD
BOD
HEXANE EXTRACTABLES
GRAMS PER MINUTE
500
400
300
200
100
0
2400 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400
TIME OF DAY

FIGURE 36



BACKGROUND LOADING
CENTRAL BUSINESS DISTRICT
TOTAL HYDROLYZABLE PHOSPHATE
ORTHO PHOSPHATE
GRAMS PER MINUTE
0
5
10
15
20
2400 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400
TIME OF DAY

FIGURE 37

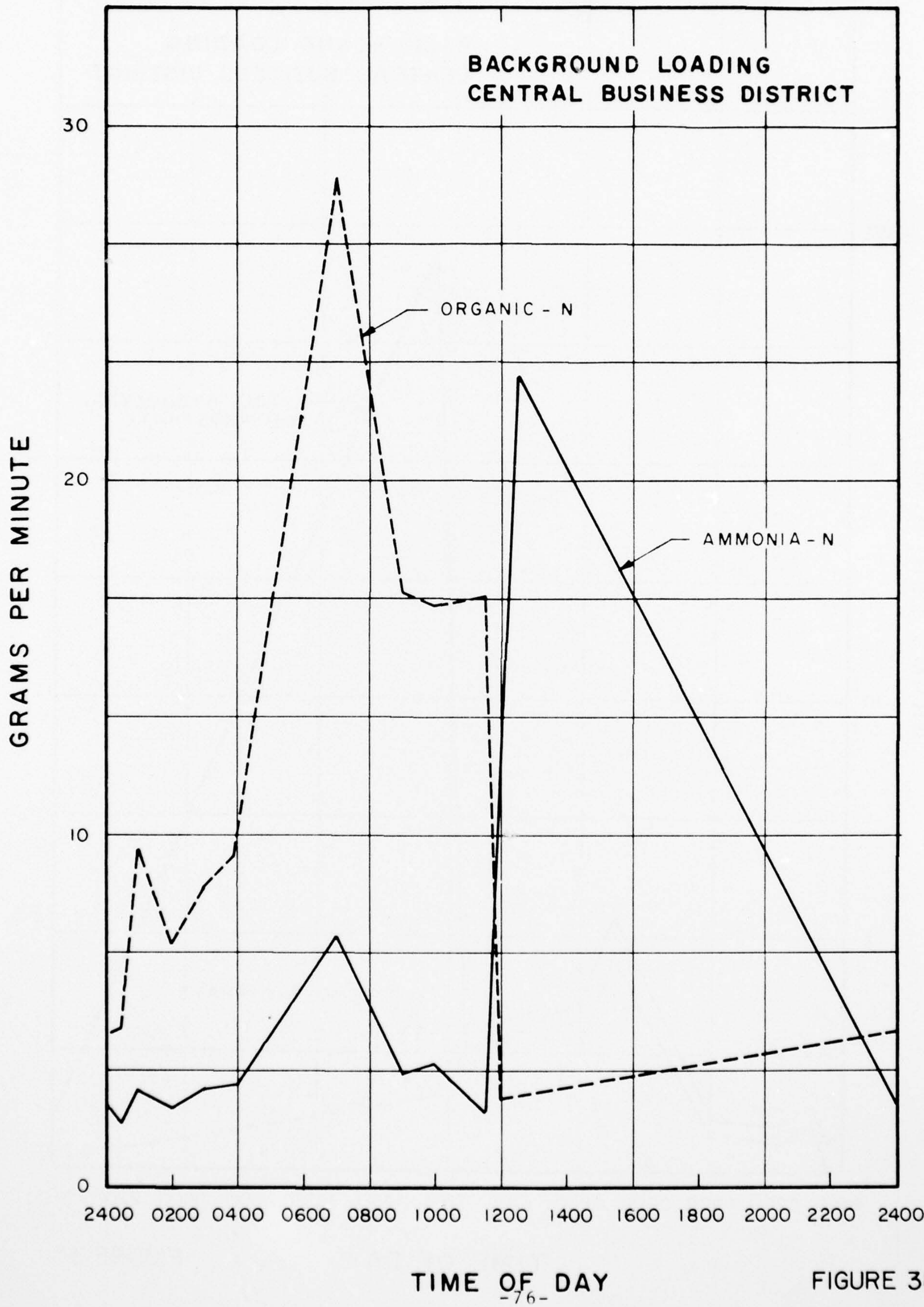

BACKGROUND LOADING
CENTRAL BUSINESS DISTRICT
ORGANIC - N
AMMONIA - N
GRAMS PER MINUTE
30
20
10
0
2400
0200
0400
0600
0800
1000
1200
1400
1600
1800
2000
2200
2400
TIME OF DAY

FIGURE 38

APPENDIX C

URBAN RUNOFF CHARACTERISTICS

INDIVIDUAL STORMS

TABLE 9
URBAN RUNOFF CHARACTERISTICS
VIEWRIDGE ONE AREA

Parameter	Mean Concentration Feb 14	Mar 10	Mar 16	June 6	Aug 16	Sept 19	Mean
Temp. C^{o}	7.3	9.1	9.4	15.8	19.0	18.0	13.1
pH	7.3	7.5	7.3	6.8	6.9	6.5	-
Cond. umho/cm	157	34	94	160	228	76	125
Turbidity, JTU	65	8	33	23	23	30	30
DO, mg/l	9.8	11.5	10.5	6.2	5.9	7.6	8.6
BOD, mg/l	34	4.9	10	49	58	22	30
COD, mg/l	88	55	59	126	176	64	95
Hexane Ext., mg/l	10	20	7.4	8.1	17	12	12
Chloride, mg/l	8.8	1.1	5.2	13	16	1.9	7.7
Sulfate, mg/l	24	2.4	13	26	29	7.0	17
Organic N, mg/l	1.3	0.64	1.5	3.5	6.5	1.9	2.6
Ammonia N, mg/l	0.17	0.11	0.20	0.18	1.1	0.13	0.32
Nitrite N, mg/l	0.22	0.08	0.10	0.04	0.15	0.08	0.11
Nitrate N, mg/l	0.72	0.18	0.70	0.38	1.7	0.35	0.67
Hydrolyzable P, mg/l	0.33	0.24	0.31	0.33	1.10	0.37	0.45
Ortho P, mg/l	0.08	0.04	0.06	0.08	0.31	0.12	0.12
Copper, mg/l	0.030	0.042	0.012	0.054	0.075	0.032	0.040
Lead, mg/l	0.42	0.10	0.45	0.22	1.3	0.13	0.44
Iron, mg/l	4.7	0.54	2.8	0.92	5.2	0.28	2.4
Mercury, mg/l	0.0006	0.0003	0.0002	0.0002	0.0002	0.0002	0.0003
Chromium, mg/l	0.016	0.010	0.012	0.09	0.012	0.010	0.025
Cadmium, mg/l	0.006	0.005	0.004	0.004	0.006	0.004	0.005
Zinc, mg/l	0.080	0.029	0.13	0.27	0.49	0.051	0.18
Sett. Solids, mg/l	107	49	29	38	50	32	51
Susp. Solids, mg/l	144	127	88	48	69	34	85
TDS, mg/l	111	25	246	185	168	68	134
Total Coliform* org/100 mls	3200	12000	7800	45000	140000	420000	28000
Fecal Coliform* org/100 mls	420	2600	550	4500	6300	12000	3600

*Medians

TABLE 10
URBAN RUNOFF CHARACTERISTICS
VIEWRIDGE TWO AREA

Parameter	Mean Concentration						
	Feb 14	Mar 10	Mar 16	June 6	Aug 16	Sept 19	Mean
Temp. C^{o}	7.9	9.0	9.4	16.4	17.7	17.1	12.9
pH	7.2	7.5	7.3	6.7	7.0	6.5	-
Cond. umho/cm	184	61	109	165	192	102	136
Turbidity, JTU	63	25	42	29	33	30	37
DO, mg/l	10.0	11.5	10.5	6.4	6.6	8.2	8.9
BOD, mg/l	20	11	9	47	75	18	30
COD, mg/l	65	63	61	170	157	63	97
Hexane Ext. mg/l	13	26	22	11	15	9.3	16
Chloride, mg/l	24	1.5	3.4	17	23	3.0	12
Sulfate, mg/l	27	5.0	8.0	28	28	10	18
Organic N, mg/l	-	-	-	2.8	6.0	1.7	3.5
Ammonia N, mg/l	-	-	0.20	0.72	0.81	0.18	0.48
Nitrite N, mg/l	0.20	0.04	0.11	0.13	0.15	0.07	0.12
Nitrate N, mg/l	0.93	0.35	0.21	0.84	1.41	0.58	0.72
Hydrolyzable P, mg/l	0.26	0.28	0.22	0.38	0.93	0.33	0.40
Ortho P, mg/l	0.05	0.04	0.06	0.14	0.28	0.13	0.12
Copper, mg/l	0.032	0.040	0.035	0.051	0.048	0.13	0.056
Lead, mg/l	0.43	0.10	0.47	0.28	-	0.30	0.32
Iron, mg/l	4.0	0.52	3.8	0.97	-	0.88	2.0
Mercury, mg/l	0.0001	0.0003	0.0003	0.0010	0.0005	0.0001	0.0004
Chromium, mg/l	0.005	0.010	0.010	0.010	0.009	0.010	0.009
Cadmium, mg/l	0.004	0.004	0.004	0.005	0.005	0.004	0.004
Zinc, mg/l	0.065	0.028	0.091	0.26	-	0.15	0.12
Sett. Solids, mg/l	118	43	47	61	188	45	84
Susp. Solids, mg/l	175	127	40	66	210	55	112
TDS, mg/l	131	64	117	191	174	70	125
Total Coliform* org/100 mls	7200	11000	8700	40000	42000	620000	26000
Fecal Coliform* org/100 mls	490	2000	490	360	6000	13000	1200

*Medians

TABLE 11
URBAN RUNOFF CHARACTERISTICS
SOUTH SEATTLE AREA

Parameter	Mar 10	Mar 16	Mean Concentrations June 6	Aug 16	Sept 19	Mean
Temp. C^o	8.1	9.4	18.0	20.1	18.2	14.8
pH	7.2	7.7	6.7	6.7	6.2	-
Cond. umho/cm	20	89	169	243	150	134
Turbidity, JTU	35	42	40	81	36	47
DO, mg/l	11.7	11.0	6.4	5.6	7.6	8.5
BOD, mg/l	2.9	5.1	38	36	14	19
COD, mg/l	7.0	56	147	156	111	95
Hexane Ext. mg/l	8.0	12	12	27	11	14
Chloride, mg/l	1.2	5.3	28	24	2.5	12.2
Sulfate, mg/l	3.6	12	30	41	44	26.1
Organic N, mg/l	0.55	0.90	1.8	2.9	2.5	1.7
Ammonia N, mg/l	0.12	0.24	0.25	0.57	0.42	0.32
Nitrite N, mg/l	0.02	0.07	0.06	0.07	0.06	0.06
Nitrate N, mg/l	0.24	0.29	0.90	1.6	1.1	0.83
Hydrolyzable P, mg/l	0.18	0.19	0.28	0.43	0.12	0.24
Ortho P, mg/l	0.03	0.05	0.10	0.14	0.08	0.08
Copper, mg/l	0.043	0.052	0.076	0.10	0.24	0.10
Lead, mg/l	0.10	0.27	0.13	0.50	0.27	0.25
Iron, mg/l	0.39	2.7	0.90	5.6	1.1	2.1
Mercury, mg/l	0.0004	0.0002	0.0006	0.0003	0.0003	0.0004
Chromium, mg/l	0.010	0.010	0.009	0.009	0.010	0.010
Cadmium, mg/l	0.005	0.005	0.004	0.006	0.004	0.005
Zinc, mg/l	0.08	0.30	0.53	0.70	0.53	0.43
Sett. Solids, mg/l	41	52	89	78	39	60
Susp. Solids, mg/l	63	91	100	109	39	80
TDS, mg/l	179	181	150	233	138	176
Total Coliform* org/100 mls	1000	360	5300	4200	14000	4200
Fecal Coliform* org/100 mls	360	20	20	30	180	30

*Medians

TABLE 12
URBAN RUNOFF CHARACTERISTICS
SOUTHCENTER

Parameter	Mean Concentration						
	Feb 14	Mar 10	Mar 16	June 6	Aug 16	Sept 19	Mean
Temp. C^{o}	6.2	8.6	9.9	18.4	18.3	18.2	13.3
pH	6.4	6.9	7.6	7.0	6.3	6.2	-
Cond. umho/cm	148	9.4	127	146	118	42	99
Turbidity, JTU	15	21	8.6	17.9	33.5	16	18.7
DO, mg/l	10.7	11.2	10.2	8.4	7.8	8.8	9.5
BOD, mg/l	4.7	4.4	11.6	10.6	36	21	15
COD, mg/l	78	48	59	79	107	46	70
Hexane Ext., mg/l	17	14	7.9	6.2	11	9.2	11
Chloride, mg/l	7.2	1.3	13.7	3.5	12.4	1.2	6.6
Sulfate, mg/l	33	3.8	24	16	20	10	18
Organic N, mg/l	0.12	0.86	1.1	1.3	3.7	1.3	1.4
Ammonia N, mg/l	0.34	0.09	0.22	0.21	0.81	0.27	0.32
Nitrite N, mg/l	0.05	0.02	0.04	0.03	0.05	0.04	0.04
Nitrate N, mg/l	0.48	0.31	0.58	0.54	1.57	0.39	0.64
Hydrolyzable P, mg/l	0.20	0.13	0.09	0.19	0.29	0.10	0.17
Ortho P, mg/l	0.03	0.03	0.01	0.07	0.11	0.04	0.05
Copper, mg/l	0.016	0.015	0.085	0.032	0.080	0.26	0.081
Lead, mg/l	0.05	0.12	0.61	0.30	1.01	0.30	0.40
Iron, mg/l	0.38	0.08	1.14	0.85	1.65	0.41	0.75
Mercury, mg/l	0.0001	-	0.0019	0.0006	-	0.0005	0.0008
Chromium, mg/l	0.015	0.010	0.010	0.092	0.31	0.005	0.074
Cadmium, mg/l	0.000	0.004	0.005	0.004	0.005	0.004	0.004
Zinc, mg/l	0.000	0.042	0.37	0.20	0.58	0.27	0.24
Sett. Solids, mg/l	31	40	18	64	66	22	40
Susp. Solids, mg/l	87	78	33	133	80	25	73
TDS, mg/l	118	12	170	64	130	41	89
Total Coliform* Org/100 mls	-	1200	490	1900	-	32000	1600
Fecal Coliform* Org/100 mls	-	-	110	370	-	10000	370

*Medians

TABLE 13
URBAN RUNOFF CHARACTERISTICS
LAKE HILLS

Parameter	Mean Concentration Mar 10	Mar 16	June 6	Aug 16	Sept 19	Mean
Temp. C°	8.5	9.7	18.2	18.4	18.0	14.6
pH	7.6	7.7	6.6	6.3	5.9	-
Cond. umho/cm	30	66	51	57	52	51
Turbidity, JTU	5.5	20	14	18	19	15
DO, mg/l	11.2	10.7	8.7	8.6	8.8	9.6
BOD, mg/l	4.5	6.7	7.8	16	7.3	8.5
COD, mg/l	68	41	82	96	54	68
Hexane Ext., mg/l	12	1.9	6.4	8.6	7.8	7.3
Chloride, mg/l	1.8	5.8	4.0	13	2.0	5.3
Sulfate, mg/l	4	4	10	13	4	7
Organic N, mg/l	0.44	0.76	2.5	2.3	1.0	1.4
Ammonia N, mg/l	0.07	0.11	0.26	0.38	0.12	0.19
Nitrite N, mg/l	0.01	0.03	0.03	0.04	0.02	0.03
Nitrate N, mg/l	[illegible]	0.43	0.57	[illegible]	[illegible]	0.51
Hydrolyzable P, mg/l	0.17	0.13	0.37	0.27	0.24	0.24
Ortho P, mg/l	0.03	0.04	0.22	0.16	0.13	0.12
Copper, mg/l	0.023	0.072	0.023	0.014	0.25	0.076
Lead, mg/l	0.15	0.26	0.18	0.49	0.27	0.27
Iron, mg/l	0.17	0.69	0.15	0.57	0.38	0.39
Mercury, mg/l	0.0003	0.0003	0.0002	0.0002	0.0004	0.0003
Chromium, mg/l	0.01	0.010	0.010	0.008	0.010	0.010
Cadmium, mg/l	0.006	0.004	0.004	0.004	0.004	0.004
Zinc, mg/l	0.023	0.043	0.075	0.13	0.14	0.082
Sett. Solids, mg/l	44	20	23	50	63	40
Susp. Solids, mg/l	64	41	35	61	69	54
TDS, mg/l	72	47	74	90	75	72
Total Coliform* Org/100 mls	2600	1800	37000	110000	110000	37000
Fecal Coliform* Org/100 mls	520	700	1400	7100	8200	1400

*Medians

TABLE 14
URBAN RUNOFF CHARACTERISTICS
HIGHLANDS

Parameter	Mar 10	Mar 16	Mean Concentrations June 6	Sept 19	Mean
Temp. C°	8.0	8.0	12.2	14.5	10.7
pH	6.9	7.6	7.0	6.2	-
Cond. umho/cm	73	173	173	109	132
Turbidity, JTU	50	2.4	11	25	22
DO, mg/l	10.3	10.5	8.3	8.7	9.4
BOD, mg/l	3.2	1.0	11	17	8.0
COD, mg/l	87	20	75	46	57
Hexane Ext. mg/l	18	2.0	8	5.9	8.5
Chloride, mg/l	3.7	11	13	2.2	7.5
Sulfate, mg/l	18	26	19	8	18
Organic N, mg/l	2.0	0.41	1.4	1.6	1.4
Ammonia N, mg/l	0.11	0.05	0.04	0.16	0.09
Nitrite N, mg/l	0.02	0.01	0.04	0.02	0.02
Nitrate N, mg/l	0.92	1.25	0.53	0.36	0.76
Hydrolyzable P, mg/l	0.52	0.12	0.22	0.53	0.35
Ortho P, mg/l	0.08	0.05	0.08	0.19	0.10
Copper, mg/l	0.032	0.150	0.016	0.280	0.120
Lead, mg/l	0.10	0.12	0.01	0.11	0.08
Iron, mg/l	0.41	0.25	0.12	0.97	0.44
Mercury, mg/l	0.0002	0.0019	0.0006	0.0005	0.0008
Chromium, mg/l	0.010	0.010	0.009	0.010	0.010
Cadmium, mg/l	0.005	0.005	0.004	0.004	0.004
Zinc, mg/l	0.032	0.050	0.042	0.15	0.068
Sett. Solids, mg/l	90	0.1	61	120	68
Susp. Solids, mg/l	173	22	65	130	98
TDS, mg/l	104	77	148	74	101
Total Coliform* Org/100 mls	1200	490	1900	32000	1600
Fecal Coliform* Org/100 mls	-	110	370	10000	370

*Medians

APPENDIX D

URBAN RUNOFF POLLUTANT LOADING

INDIVIDUAL STORMS

TABLE 15

URBAN RUNOFF CHARACTERISTICS

CENTRAL BUSINESS DISTRICT

Parameter	Mar 10	Mar 16	Mean Concentration June 6	Aug 16	Sept 19	Mean
Temp. C*	-	12.8	17.9	18.1	17.8	16.6
pH	7.1	7.7	6.4	6.5	5.4	6.6
Cond. umho/cm	74	271	234	256	214	210
Turbidity, JTU	45	53	38	34	44	43
DO, mg/l	10.8	7.4	4.7	5.3	6.6	7.0
BOD, mg/l	18	24	15	37	15	22
COD, mg/l	85	94	32	100	22	66
Hexane Ext., mg/l	5.1	1.4	-	16	5.1	6.8
Chloride, mg/l	13	-	41	31	10	24
Sulfate, mg/l	7	22	35	40	20	25
Organic N, mg/l	-	1.3	-	2.0	0.16	1.1
Ammonia N, mg/l	0.08	1.1	-	2.1	0.27	0.88
Nitrite N, mg/l	0.04	0.12	0.19	0.14	0.14	0.12
Nitrate N, mg/l	0.63	0.39	0.71	1.12	0.70	0.72
Hydrolyzable P, mg/l	0.26	0.61	-	1.82	0.15	0.71
Ortho P, mg/l	0.010	0.046	0.17	0.40	-	0.16
Copper, mg/l	0.03	0.70	0.27	0.67	0.51	0.44
Lead, mg/l	0.11	0.28	0.37	0.72	0.36	0.37
Iron, mg/l	0.44	3.6	1.5	2.6	2.1	2.0
Mercury, mg/l	-	0.0006	-	-	0.0004	0.0005
Chromium, mg/l	0.010	0.52	0.32	0.40	0.16	0.28
Cadmium, mg/l	0.0040	0.0089	0.0060	0.030	0.018	0.013
Zinc, mg/l	0.18	0.37	0.71	0.83	2.2	0.86
Sett. Solids, mg/l	79	47	151	172	116	113
Susp. Solids, mg/l	126	145	194	339	147	190
TDS, mg/l	81	135	157	570	96.7	208
Tot. Coliform * org./100 mls	37000	6500000	4100000	5200000	-	4600000
F. Coliform * org./100 mls	-	440000	-	-	-	440000

* Medians

Note: Due to limited background data from this area, these values are approximate

AD-A042 168 KCM-WRE/YTO SEATTLE WASH F/G 8/8

ENVIRONMENTAL PLANNING FOR THE METROPOLITAN AREA CEDAR-GREEN RI--ETC(U)

DEC 74 G FARRIS, R G SWARTZ, N R WELLS

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TABLE 16
URBAN RUNOFF POLLUTANT LOADING
VIEWRIDGE ONE

Parameter	Feb 14	Mar 10	Mar 16	June 6	Aug 16	Sept 19	Mean
	Loading, pounds/acre/year						
BOD	2.5	23	1.7	1.9	12	1.7	7.1
COD	6.5	260	10	4.8	35	4.9	54
Hexane Ext.	0.70	96	1.3	0.31	3.5	0.92	17
Chloride	0.64	5.1	0.90	0.49	3.3	0.15	1.8
Sulfate	1.8	11	2.2	0.10	5.9	0.51	3.6
Organic N	0.094	3.0	.26	.13	1.3	.14	0.8
Ammonia N	0.012	0.52	0.036	0.007	0.23	0.01	0.14
Nitrite N	0.016	0.039	0.018	0.002	0.031	0.006	0.019
Nitrate N	0.053	0.86	0.055	0.014	0.34	0.026	0.22
Hydrolyzable P	0.024	1.15	0.054	0.012	0.22	0.028	0.25
Ortho P	0.006	0.20	0.010	0.003	0.062	0.009	0.048
Copper	0.002	0.20	0.002	0.002	0.014	0.002	0.037
Lead	0.031	0.49	0.078	0.008	0.27	0.01	0.15
Iron	0.34	2.56	0.49	0.035	1.05	0.022	0.75
Chromium	0.001	0.047	0.002	0.003	0.003	0.001	0.009
Cadmium	0.000	0.020	0.001	0.000	0.001	0.000	0.004
Zinc	0.006	0.14	0.022	0.010	0.10	0.004	0.05
Sett. Solids	7.8	230	5.0	1.5	9.7	2.5	42.7
Susp. Solids	11	600	15	1.8	14	2.6	107
TDS	8.1	120	43	7.0	34	5.2	36

TABLE 17
URBAN RUNOFF POLLUTANT LOADING
VIEWRIDGE TWO

	Loading, pounds/acre/year						
Parameter	Feb 14	Mar 10	Mar 16	June 6	Aug 16	Sept 19	Mean
BOD	3.5	462	2.9	6,1	74	3.2	92
COD	22	1850	26	34	92	19	340
Hexane Ext.	7.8	820	24	2.2	8.8	1.6	144
Chloride	18	50	-	3.5	25	1.4	20
Sulfate	15	177	-	4.5	19	4.7	44
Organic N	-	-	-	0.23	3.8	0.48	1.5
Ammonia N	-	-	0.071	0.22	0.20	0.080	0.14
Nitrite N	0.092	1.6	0.057	0.039	0.10	0.018	0.32
Nitrate N	0.54	14	-	0.22	0.67	0.28	3.1
Hydrolyzable P	0.095	8.0	-	0.066	0.47	0.084	1.8
Ortho P	0.016	0.93	0.021	0.032	0.16	0.042	0.20
Copper	0.016	0.99	0.038	0.007	-	0.086	0.23
Lead	0.21	2.7	0.21	0.052	-	0.17	0.67
Iron	1.6	13	2.5	0.15	-	0.55	3.6
Chromium	0.002	0.21	0.004	-	0.004	0.004	0.04
Cadmium	0.002	0.103	0.003	0.001	0.002	0.002	0.019
Zinc	0.025	0.70	-	0.035	-	0.10	0.22
Sett. Solids	64	1000	37	14	310	20	240
Susp. Solids	99	3310	-	13	320	27	760
TDS	74	2770	-	29	130	22	610

TABLE 18
URBAN RUNOFF POLLUTANT LOADING
SOUTH SEATTLE

Parameter	Mar 10	Mar 16	June 6	Aug 16	Sept 19	Mean
	Loading, pounds/acre/year					
BOD	8.6	1.2	9.1	1.1	16	7.1
COD	21	13	35	4.9	122	39
Hexane Ext.	24	2.8	2.9	0.85	12	8.4
Chloride	3.6	1.2	6.8	0.75	2.8	3.0
Sulfate	11	2.8	7.2	1.3	48	14
Organic N	1.6	0.21	0.43	0.09	2.8	1.0
Ammonia N	0.36	0.055	0.059	0.018	0.46	0.19
Nitrite N	0.048	0.016	0.015	0.002	0.068	0.030
Nitrate N	0.70	0.067	0.21	0.049	1.19	0.44
Hydrolyzable P	0.54	0.044	0.066	0.013	0.13	0 16
Ortho P	0.080	0.011	0.023	0.004	0.083	0.040
Copper	0.127	0.012	0.[illegible]	0.003	0.26	0.085
Lead	0.28	0.062	[illegible]	0.016	0.30	0.14
Iron	1.2	0.64	0.21	0.17	1.2	0.68
Chromium	0.030	0.002	0.002	0.000	0.011	0.009
Cadmium	0.013	0.001	0.001	0.000	0.004	0.004
Zinc	0.26	0.71	0.13	0.022	0.58	0.21
Sett. Solids	121	12	21	2.4	42	40
Susp. Solids	188	21	24	3.4	42	56
TDS	531	43	36	7.3	151	153

TABLE 19
URBAN RUNOFF POLLUTANT LOADING
SOUTHCENTER

Parameter	Loading, pounds/acre/year						
	Feb 14	Mar 10	Mar 16	June 6	Aug 16	Sept 19	Mean
BOD	.30	15	2.7	12	26	29	14
COD	4.6	158	14	93	78	63	68
Hexane Ext.	1.0	45	1.8	7.3	8.0	13	13
Chloride	.42	4.3	3.2	4.2	8.9	1.4	3.7
Sulfate	2.0	13	5.4	19	14	14	11
Organic N	0.007	2.9	0.24	1.5	2.6	1.7	1.5
Ammonia N	0.020	0.28	0.050	0.25	0.58	0.37	0.26
Nitrite N	0.003	0.052	0.009	0.040	0.037	0.051	0.032
Nitrate N	0.028	1.02	0.13	0.64	1.14	0.53	0.58
Hydrolyzable P	0.011	0.44	0.020	0.22	0.21	0.14	0.17
Ortho P	0.002	0.106	0.003	0.077	0.077	0.047	0.052
Copper	0.001	0.051	0.020	0.036	0.06	0.36	0.09
Lead	0.003	0.40	0.14	0.35	0.73	0.41	0.34
Iron	0.022	0.25	0.26	1.00	1.19	0.56	0.55
Chromium	0.001	0.033	0.002	0.11	0.22	0.007	0.062
Cadmium	0.000	0.013	0.001	0.004	0.004	0.005	0.004
Zinc	0.000	0.14	0.085	0.23	0.42	0.37	0.21
Sett. Solids	1.8	133	4.0	76	47	30	49
Susp. Solids	5.0	259	7.5	157	58	34	87
TDS	6.9	39	39	75	94	56	52

TABLE 20
URBAN RUNOFF POLLUTANT LOADING
LAKE HILLS

Parameter	Mar 10	Mar 16	June 6	Aug 16	Sept 19	Mean
	Loading, pounds/acre/year					
BOD	5.8	2.6	0.56	7.3	1.7	3.6
COD	87	16	5.8	45	12	33
Hexane Ext.	15	0.75	0.45	4.1	1.8	4.4
Chloride	2.4	2.2	0.26	6.0	0.45	2.3
Sulfate	5.0	1.6	0.74	6.5	1.0	3.0
Organic N	0.56	0.29	0.17	1.1	0.24	0.47
Ammonia N	0.089	0.044	0.018	0.177	0.027	0.071
Nitrite N	0.013	0.008	0.002	0.016	0.005	0.009
Nitrate N	0.38	0.17	0.040	0.44	0.078	0.22
Hydrolyzable P	0.22	0.050	0.026	0.13	0.055	0.096
Ortho P	0.036	0.015	0.016	0.073	0.029	0.034
Copper	0.035	0.028	0.002	0.007	0.057	0.026
Lead	0.19	0.10	0.014	0.23	0.062	0.12
Iron	0.22	0.27	0.012	0.27	0.087	0.17
Chromium	0.013	0.004	0.001	0.004	0.002	0.005
Cadmium	0.006	0.002	0.000	0.002	0.001	0.002
Zinc	0.029	0.017	0.005	0.06	0.033	0.029
Sett. Solids	56	7.6	1.7	23	15	21
Susp. Solids	82	16	2.5	29	16	29
TDS	92	18	5.2	43	17	35

TABLE 21
URBAN RUNOFF POLLUTANT LOADING
HIGHLANDS

Parameter	Mar 10	Mar 16	June 6	Sept 19	Mean
	Loading, pounds/acre/year				
BOD	1.2	0.64	0.082	0.38	0.58
COD	33	13	0.56	1.0	12
Hexane Ext.	6.5	1.2	0.061	0.13	2.0
Chloride	1.4	6.8	0.095	0.049	2.1
Sulfate	6.6	16.1	0.14	0.19	5.8
Organic N	0.76	0.26	0.01	0.036	0.27
Ammonia N	0.04	0.03	0.000	0.004	0.02
Nitrite N	0.008	0.006	0.000	0.000	0.004
Nitrate N	0.34	0.78	0.004	0.008	0.28
Hydrolyzable P	0.20	0.072	0.002	0.012	0.071
Ortho P	0.029	0.033	0.001	0.004	0.017
Copper	0.012	0.094	0.000	0.006	0.028
Lead	0.037	0.072	0.000	0.002	0.028
Iron	0.15	0.16	0.001	0.022	0.08
Chromium	0.004	0.006	-	0.000	0.003
Cadmium	0.001	0.003	-	0.000	0.002
Zinc	0.012	0.029	-	0.003	0.015
Sett. Solids	33.6	0.062	0.46	2.7	9.2
Susp. Solids	65	14	0.49	2.9	21
TDS	39	48	1.1	1.6	22

TABLE 22

URBAN RUNOFF POLLUTANT LOADING

CENTRAL BUSINESS DISTRICT

Parameter	Mar 10	Mar 16	Loading, pounds/acre/year June 6	Aug 16	Sept. 19	Mean
BOD	73	34	12	402	21	110
COD	339	135	27	1100	31	325
Hexane Ext.	20	2.0	-	157	7.3	47
Chloride	55	-	35	344	14	113
Sulfate	28	32	30	44	28	32
Organic N	-	1.9	-	22	0.3	8.0
Ammonia N	0.34	1.6	-	23	0.36	6.2
Nitrite N	0.14	0.17	0.16	1.55	0.20	0.44
Nitrate N	2.6	0.55	0.62	12.4	0.99	3.6
Hydrolyzable P	1.0	0.88	-	20.1	0.21	5.5
Ortho P	0.036	0.066	0.14	4.4	-	1.2
Copper	0.13	1.0	0.23	7.4	0.72	1.9
Lead	0.45	0.40	0.31	7.9	0.51	1.9
Iron	1.8	5.3	1.3	29	2.9	8.0
Chromium	0.04	0.77	0.27	414	2.2	1.6
Cadmium	0.016	0.013	0.005	0.33	0.026	0.079
Zinc	0.71	0.54	0.60	9.1	3.1	2.9
Sett. Solids	318	68	128	1890	164	511
Susp. Solids	507	212	164	3720	208	964
TDS	326	197	132	6280	136	1410

Note: Due to limited background data from this area, these values are approximate

APPENDIX E

The quality data for the Water Quality and Quantity Monitoring project for the RIBCO Urban Runoff and Basin Drainage Study is on file at the Metro Office. The data may be obtained by writing to the following address:

Municipality of Metropolitan Seattle
410 W. Harrison Street
Seattle, Washington 98119

An example of the computer list-out of quality data follows.

RIBCO URBAN RUNOFF AND BASIN DRAINAGE STUDY
WATER QUALITY SA[illegible]ING PROGRAM
STORM OF FEB[illegible]4, 1973

VIEW RIDGE NO.1
SINGLE FAMILY RESIDENTIAL 630.0 ACRES

TIME HR MIN	FLOW (CFS)	TEMP (DEG. C)	DO (MG/L)	PH	TURB (JTU)	COND (M MOH/CM)	BOD (MG/L)	COD (MG/L)
13 0	0.100	8.00	11.70	7.30	2.00	290.00	1.30	20.00
13 30	0.100	8.00	11.70	7.30	2.00	290.00	1.30	20.00
13 45	0.100	8.00	11.60	7.30	2.00	290.00	1.00	18.00
14 15	0.150	8.00	11.60	7.30	2.00	290.00	1.00	18.00
14 47	0.481	7.80	11.70	7.40	3.00	300.00	8.00	21.00
15 7	0.686	7.20	9.50	7.30	55.00	210.00	94.00	192.00
15 26	0.620	7.20	9.70	7.40	85.00	194.00	52.00	131.00
15 46	0.522	7.50	9.90	7.30	55.00	178.00	20.00	53.00
16 4	0.564	7.50	9.90	7.20	42.00	178.00	25.00	71.00
16 21	0.600	7.40	10.10	7.30	46.00	164.00	17.10	61.00
17 17	0.461	7.40	10.10	7.30	46.00	164.00	17.10	61.00
17 34	0.386	7.50	10.40	7.30	64.00	175.00	12.20	41.00
18 33	0.270	7.50	10.40	7.30	64.00	175.00	12.20	41.00
18 53	0.237	7.50	10.50	7.30	40.00	167.00	13.00	56.00
20 0	0.100	7.50	10.50	7.30	40.00	167.00	13.00	56.00
TOTAL POUNDS OFF WATERSHED							13.171	36.693
WASHOFF LOAD POUNDS/ACRE							0.021	0.058
WASHOFF LD/YEAR POUNDS/ACRE/YEAR NO. DRY DAYS(3)							2.544	7.086

RIBCO URBAN RUNOFF AND BASIN DRAINAGE STUDY
WATER QUALITY SAMPLING PROGRAM
STORM OF FEBRUARY 14, 1973

VIEW RIDGE NO.1
SINGLE FAMILY RESIDENTIAL 630.0 ACRES

TIME HR MIN	FLOW (CFS)	SET-S	SS	TDS	CL (MG/L)	H-EXT (MG/L)	TOTAL COLIFORMS	FECAL (MPN/100 ML)
		--------SOLIDS (MG/L)-------						
13 0	0.100	1.20	6.00	220.00	4.20	2.00	1800.	55.
13 30	0.100	1.20	6.00	220.00	4.20	2.00	1800.	55.
13 45	0.100	2.70	4.00	220.00	3.90	4.00	1600.	50.
14 15	0.150	2.70	4.00	220.00	3.90	4.00	1600.	50.
14 47	0.481	1.50	12.00	190.00	4.20	6.46	1250.	60.
15 7	0.686	210.00	216.00	130.00	6.60	8.00	3250.	155.
15 26	0.620	420.00	416.00	130.00	6.60	9.00	17000.	605.
15 46	0.522	97.00	170.00	110.00	6.00	7.00	21500.	860.
16 4	0.564	34.00	74.00	140.00	8.10	6.00	14500.	1040.
16 21	0.600	28.00	70.22	130.00	9.00	8.00	13000.	370.
17 17	0.461	28.00	57.78	130.00	9.00	8.00	13000.	370.
17 34	0.386	17.00	54.00	140.00	8.70	8.00	2050.	415.
18 33	0.270	17.00	54.00	140.00	8.70	8.00	2050.	415.
18 53	0.237	13.00	40.00	120.00	8.70	7.00	2900.	640.
20 0	0.100	13.00	40.00	120.00	8.70	7.00	2900.	640.
TOTAL POUNDS OFF WATERSHED		40.565	55.454	76.639	3.997	3.917		
WASHOFF LOAD POUNDS/ACRE		0.064	0.088	0.122	0.006	0.006		
WASHOFF LD/YEAR POUNDS/ACRE/YEAR		7.834	10.709	14.801	0.772	0.756		

NO. DRY DAYS(3)

RIBCO URBAN RUNOFF AND BASIN DRAINAGE STUDY
WATER QUALITY SAMPLING PROGRAM
STORM OF FEBRUARY 14, 1973

VIEW RIDGE NO.1
SINGLE FAMILY RESIDENTIAL 630.0 ACRES

TIME HR MIN	FLOW (CFS)	T-HYDR PHOSPHORUS	ORTHO (MG/L)	K-NIT	NH-3	NO-2 NITROGEN (MG/L)	NO-2 + NO-3	SO-4 (MG/L)
13 0	0.100	0.15	0.05	0.66	0.06	0.02	2.30	30.00
13 30	0.100	0.15	0.05	0.66	0.06	0.02	2.30	30.00
13 45	0.100	0.12	0.05	0.61	0.08	0.02	2.20	30.00
14 15	0.150	0.12	0.05	0.61	0.08	0.02	2.20	30.00
14 47	0.481	0.14	0.05	0.50	0.24	0.02	2.40	28.96
15 7	0.686	0.26	0.06	1.20	0.30	0.19	1.20	28.32
15 26	0.620	0.34	0.14	1.40	0.20	0.19	0.90	27.70
15 46	0.522	0.32	0.10	1.20	0.22	0.17	0.80	27.05
16 4	0.564	0.51	0.12	1.00	0.32	0.22	1.30	26.47
16 21	0.600	0.20	0.06	1.50	0.06	0.20	0.80	25.92
17 17	0.461	0.20	0.06	1.50	0.06	0.20	0.80	24.11
17 34	0.386	0.18	0.04	0.93	0.06	0.16	1.10	23.56
18 33	0.270	0.18	0.04	0.93	0.06	0.16	1.10	21.65
18 53	0.237	0.14	0.05	0.70	0.06	0.15	0.90	21.00
20 0	0.100	0.14	0.05	0.70	0.06	0.15	0.90	21.00

	T-HYDR PHOSPHORUS	ORTHO	K-NIT	NH-3	NO-2	NO-2 + NO-3	SO-4
TOTAL POUNDS OFF WATERSHED	1.501E-01	3.650E-02	5.911E-01	7.415E-02	8.474E-02	6.368E-01	1.389E 01
WASHOFF LOAD POUNDS/ACRE	2.382E-04	5.793E-05	9.383E-04	1.177E-04	1.345E-04	1.011E-03	2.205E-02
WASHOFF LB/YEAR POUNDS/ACRE/YEAR NO. DRY DAYS(3)	2.898E-02	7.048E-03	1.142E-01	1.432E-02	1.637E-02	1.230E-01	2.682E 00

RIBCO URBAN RUNOFF AND BASIN DRAINAGE STUDY
WATER QUALITY SAMPLING PROGRAM
STORM OF FEBRUARY 14, 1973

VIEW RIDGE NO.1
SINGLE FAMILY RESIDENTIAL 630.0 ACRES

TIME HR MIN	FLOW (CFS)	CU	PB	FE	HG	CR	CD	AS	ZN
		HEAVY METALS (UG/L)							
13 0	0.100	10.0	100.0	260.0	0.6	10.0	4.0	0.0	6.0
13 30	0.100	10.0	100.0	260.0	0.6	10.0	4.0	0.0	6.0
13 45	0.100	10.0	100.0	240.0	0.4	10.0	3.9	0.0	8.0
14 15	0.150	10.0	100.0	240.0	0.4	10.0	3.9	0.0	8.0
14 47	0.481	10.0	100.0	230.0	0.2	10.0	3.9	0.0	5.0
15 7	0.686	20.0	300.0	2400.0	0.1	40.0	3.9	0.0	68.0
15 26	0.620	20.0	400.0	7430.0	0.2	10.0	3.9	0.0	88.0
15 46	0.522	30.0	400.0	2360.0	0.2	10.0	3.9	0.0	82.0
16 4	0.564	20.0	300.0	1400.0	0.2	30.0	3.9	0.0	63.0
16 21	0.600	30.0	400.0	2100.0	0.4	10.0	3.9	0.0	64.0
17 17	0.461	30.0	400.0	2100.0	0.4	10.0	3.9	0.0	64.0
17 34	0.386	30.0	400.0	8600.0	0.5	10.0	3.9	0.0	62.0
18 33	0.270	30.0	400.0	8600.0	0.5	10.0	3.9	0.0	62.0
18 53	0.237	30.0	300.0	2100.0	0.9	10.0	3.9	0.0	67.0
20 0	0.100	30.0	300.0	2100.0	0.9	10.0	3.9	0.0	67.0
TOTAL POUNDS OFF WATERSHED		1.308E-02	1.764E-01	1.815E 00	2.000E-04	7.568E-03	2.098E-03	0.0	3.122E-02
WASHOFF LOAD POUNDS/ACRE		2.075E-05	2.800E-04	2.881E-03	3.175E-07	1.201E-05	3.331E-06	0.0	4.956E-05
WASHOFF LD/YEAR POUNDS/ACRE/YEAR NO. DRY DAYS(3)		2.525E-03	3.407E-02	3.505E-01	3.862E-05	1.461E-03	4.052E-04	0.0	6.029E-03

TOTAL RUNOFF = 6062.0(CU FT) TOTAL RAINFALL(0.07 IN) = 160082.9(CU FT) PERCENT RUNOFF = 3.787